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HUGHES TOOL COMPANY · AIRCRAFT DIVISION

Culver City, California

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Report 285-13 (62-13)

CONTRACT NO. AF 33(600)-30271

HOT CYCLE ROTOR SYSTEM STRUCTURAL ANALYSIS VOL. I

March 1962

Revised June 1962

HUGHES TOOL COMPANY -- AIRCRAFT DIVISION
Culver City, California

For

Commander

Aeronautical Systems Division

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FOREWORD

This report has been prepared by Hughes Tool Company -- Aircraft Division under USAF Contract AF 33(600)-30271 "Hot Cycle Pressure Jet Rotor System," D/A Project Number 9-38-01-000, Subtask 616.

The Hot Cycle Pressure Jet Rotor System is based on a principle wherein the exhaust gases from high pressure ratio turbojet engine(s) located in the fuselage are ducted through the rotor hub and blades and are exhausted through a nozzle at the blade tips. Forces thus produced drive the rotor.

The objective of this contract was to prove feasibility of the Hot Cycle Pressure Jet concept by design, fabrication and test of a complete rotor.

This report covers that portion of the work pertaining to analysis of the design prior to whirl test, specifically the analytical substantiation of the structural components. It is in partial fulfillment of Item 4e, covering Analysis Pertaining to Design of the Rotor System, performed under Item 4b of the contract. Although the main body of the report was completed some time ago, its submittal was withheld in order to permit correlation with recently obtained experimental and test data.

TABLE OF CONTENTS

SUMMARY

This report presents the structural design and analysis for the Hot Cycle Rotor System. The report is divided into three volumes as follows:

(1) Volume I

Structural Criteria, Materials Selection, Weight Analysis, and Design Loads.

(2) Volume II

Rotor Blade Structural Analysis

(3) Volume III

Rotor Hub Structural Analysis and Control System Analysis.

The primary objective of the design was to produce a rotor system which, through whirl testing and fatigue testing, would prove the feasibility of the Hot Cycle concept. Structural Analysis, presented in Section 5, provides analytical substantiation of the structural components both for maximum maneuver conditions and for repeated fatigue loading.

STRUCTURAL DESCRIPTION

The Hot Cycle Rotor, shown schematically in Figure I and complete in the photograph of Figure II consists of three blades of constant chord which are retained by straps to the central hub. Propulsion is provided by hot gases, produced for this configuration by two General Electric T64 gas generators, * which are ducted out the blades and ejected at the tip cascades. The floating hub is attached to the main rotor shaft thru a gimbal arrangement. The shaft is mounted to the pylon supporting structure thru two sets of bearings, displaced in the vertical direction, to react moments and side loads. Rotor thrust is reacted at the lower bearing.

(a) Rotor Blade

The rotor blade has two titanium spars that are continuous from the blade root (Sta. 24) to the tip (Sta. 333). The spars are designed to resist the centrifugal force loads, flapwise and chordwise bending moments, and an unbalanced spanwise duct pressure load.

The remainder of the blade is made in segments (approximately one foot in length in the constant section region). The main segments, which are connected by flexible couplings, act as spacers between the front and rear spars and contain the hot gas ducts. Trailing edge and nose cap sections which attach to the main segments with flush screws complete the blade airfoil.

The blade ducts which transfer the hot gases from the hub to the tip cascade are an integral part of the blade section from (Sta. 90) outboard to the tip. The root section of the duct is supported from the hub by a gimbal and ball seal which allows flapping motion. A sliding lip seal at (Sta. 42) allows for expansion and feathering motion. Outboard of the lip seal the duct is supported from the blade and undergoes a transition from a single circular duct to the twin ducts of the outboard constant blade section.

Stainless steel strap packs at the front and rear of each blade attach the blades to the hub. Blade loads are transferred from the spars to the straps through attachment fittings located between blade (Stations 63 and 73). The straps restrain the blade in the chordwise direction but allow freedom in coning and pitch. A feathering ball, attached to the blade root structure (Sta. 19) and mounted in a fabroid bearing in the hub structure, transfers shear loads from blade to hub.

* For initial whirl testing, propulsion gases were supplied by a J57 turbojet engine.

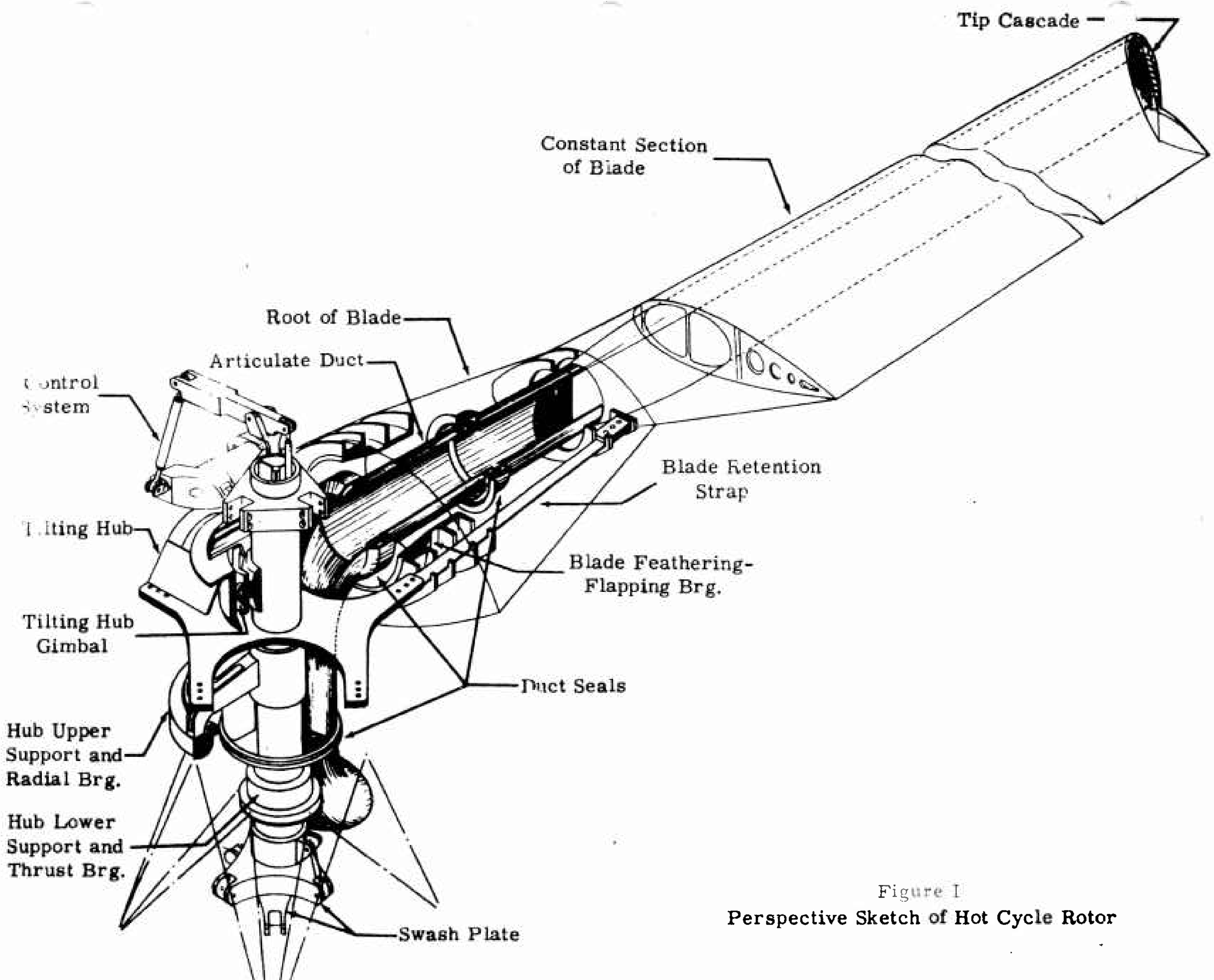


Figure I
Perspective Sketch of Hot Cycle Rotor

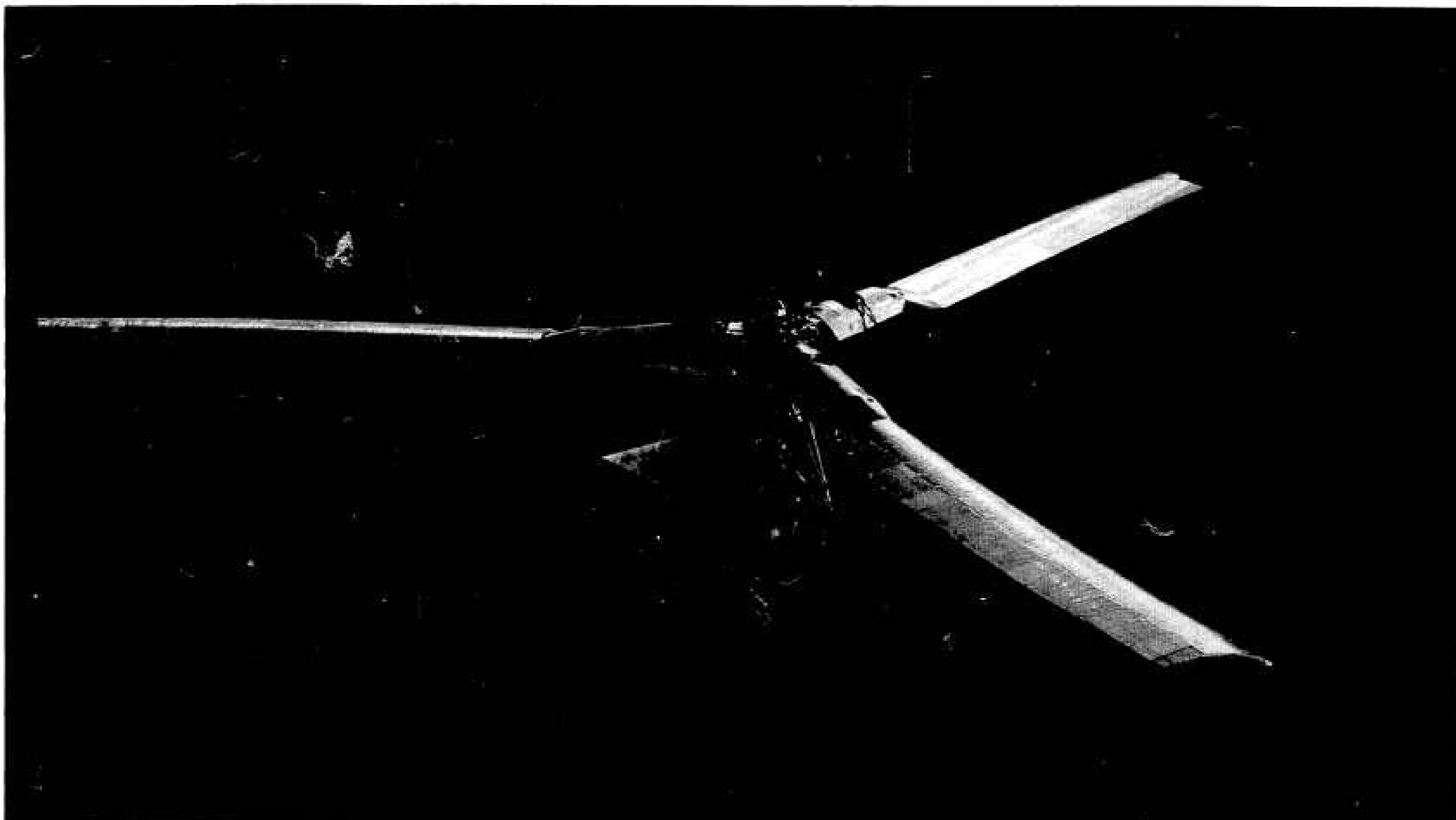


Figure II. Hot Cycle Rotor Assembly

(b) Rotor Hub and Shaft

The rotor hub and shaft form the center of the rotor system and provide the means for collecting and transferring rotor lift loads to the pylon supporting structure. The hub structure contains the root mounting structure for the blade retention straps, feathering bearing and the articulate duct. All blade loads with the exception of lift and rotor in-plane side loads are balanced out within the hub. The hub is attached to the main rotor shaft thru a gimbal at water line +4.25. Mounting of the main rotor shaft to the pylon supporting structure is accomplished by two bearings; the upper one at W. L. -8.25 which reacts side or radial load only, and the lower bearing at W. L. -36.95 which reacts radial and thrust (or lift) loads. The hub is a built-up structure of alloy steel plates and fittings and the shaft is a tubular machined part of 4340 steel (HT 160-180KSI).

(c) Control System

The controls for the rotor are operated by three large servo cylinders, mounted in the tower, which attach to the stationary swashplate, Vertical links, attached at the periphery of the rotating swashplate, actuate beams which in turn operate and position the main control rods, located inside the rotor shaft. At the upper end of the shaft the control rods emerge and thru a system of beams, levers and links transmit the control motion to the blade thru the pitch arm which attaches to the forward face of the blade root structure. For cost savings and expediency in design and manufacture the control system parts were designed to simple shapes, at some cost in excess weight for the initial rotor testing. These parts can be readily redesigned to produce a more nearly optimum configuration.

SECTION I

STRUCTURAL DESIGN CRITERIA

CONTENTS

1.1 INTRODUCTION

This section presents the structural design criteria for the Hot Cycle Rotor. The rotor is a three-bladed configuration with coning blades and floating hub. Design parameters of the rotor system are based on a vehicle gross weight of 15,300 pounds. Power is provided by two GE T-64 engines.

Maximum design maneuver load factor is 2.5g limit with an ultimate safety factor of 1.5. Maximum design loads are to be considered in combination with maximum temperature and pressure.

The design objective for service life is 1000 hours. Inasmuch as it is virtually impossible to predict an accurate vibratory load spectrum, design for fatigue is based on a weighted fatigue condition. The cyclic load level for this condition is estimated at 75% of the approach-to-land condition. All structural components are designed for infinite life at the stress levels imposed by the Weighted Fatigue condition.

1.2 GENERAL PARAMETERS

A. Design Gross Weight — 15,300 lb.

B. Type Rotor System — Floating hub, coning blade

C. Duct Area in each Blade — 54.8 sq. in.

D. Blade Utilization — 45.3%

E. Cruise Speed — 100 knots

F. Blade Tip Speed

1. Hovering, cruise and maneuver — 700 fps

2. Over-rev (normal x 1.25) — 875 fps at blade pitch = 0^{o} at 3/4 radius

G. Engine — GE T-64 (two)

H. Engine Discharge

	Temp. R	Temp. F	Pres. Ratio	Pres. (psig)	Gas Mass Flow lb/sec
1. Current Engine					
a. Cruise at S. L. Std (Normal Rated Power)	1499	1039	2.61	23.6	23.8
b. Take-off at S. L. Std (Military Rated Power)	1577	1117	2.83	26.9	25.0
2. Advanced Engine					
a. Cruise at S. L. Std (Normal Rated Power)	1577	1117	2.83	26.9	25.0
b. Take-off at S. L. Std (Military Rated Power)	1644	1184	2.97	29.0	26 0

1.3 BLADE CONFIGURATION

A.	Number of Blades	3
B.	Airfoil	NACA 0018
C.	Chord	31.5 inches
D.	Radius	27.5 ft (330 in.) to center of tip nozzle
E.	Twist	8° washout (in 330 inches)
F.	Feathering Point	26.2% chord (8.25 in. from LE)
G.	Pitch Setting (Built In)	At the 3/4 radius, pitch = $+7.6^{\circ}$ in relation to plane of rotation
H.	Deformation of Contour Permitted	Limited to total (both sides) of 1% (.315 in.) of chord. If practical, there should be no reverse curvature when air-foil is deformed by temperature or load.
I.	Balance Desired	Incremental balance at or ahead of 25% chord point (7.875 from LE) from Sta 100 to tip.
J.	Natural Frequency Required	

1. Normal

   $N_{r_1} > 2.2 < 2.8$/Rev

   $N_{r_2} > 4.2 < 4.8$/Rev

2. Chordwise

   $N_{r_1} > 1.3 < 1.7$/Rev

Through range of tip speeds from 665 to 735 fps.

1.4 LOADS AND LOAD FACTORS

A. Load Factor in Maneuver	2.5g limit at design gross weight (per MIL-S-8698 (ASG) Paragraph 3.1.10)
B. Load Factor in Ground Flapping	
1. Blade Droop Stop & Hub 10° Tilt Stop	2.5g limit
2. Hub 2° Tilt Stop	2g limit
C. Wind Loads	Shall be those resulting from a 40-knot wind from any horizontal direction (per MIL-S-8698) (ASG) Paragraph 3.4.6.2)
D. Rotor Starting Condition	Static thrust (max.) of 500 lb/blade at blade tips reacted by rotational inertia of rotor. Blades in -2°, 1g drooped position. Rotational speed is zero.
E. External Chordwise Pressure Distribution, Cruise and 2.5g Maneuver Condition	Use data in HTC-AD Report No. 285-7, "Hot Cycle Rotor System, Item 3", pp. 45-46, Figs. 25, 26 & 27, and increase values by ratio of tip speed squared $\left(\frac{700^2}{650^2} = 1.16\right)$ and add 2.1 psi from 55% to 85% chord. (Inertia loads are included.) In addition, buffeting fatigue of blade aft skins must be guarded against by comparing gages and panel sizes with those of existing high speed aircraft.

F. Blade Torsion Loads

1. Cruise Condition
(coning = 4°, tilt = 0° to 3° aft) 6,550 ± 13,860 ip limit

2. Weighted Fatigue Condition
(coning = 4°, tilt = 0° to 6° aft) 13,100 ± 25,140 ip limit

3. Maneuver, 2-1/2g recovery
(coning = 10°, tilt = 10 aft) 20,170 ± 32,300 ip limit

Note: a. Positive value indicates blade nose down.

b. Values given include strap torsion.

c. Steady torsion should be checked in both directions.

d. To be conservative, when analyzing swashplate and lower controls, critical phasing of above loads from each of the three blades should be used.

e. In lieu of a more accurate dynamic analysis, an arbitrary dynamic (limit) factor of 1.25 shall be used for the ultimate conditions of blade root torsion (Item F. 3 above). This factor may be reduced to 1.10 between actuating cylinders and the top of the mast. The usual 1.5 ultimate factor is also required.

f. The hydraulic cylinder load input shall be capable of supplying sufficient load to actuate the rotor blades under the design maneuvers (Item F. 1 and F. 3 above).

g. The hydraulic servo system shall be restricted to provide a rate of swashplate travel of 20 deg in no less than 0.50 nor more than 0.75 sec.

h. For whirl tower test only, the control loads may be reduced as follows:

(1) Steady component - same as corresponding flight values.

(2) Cyclic component - 40% of corresponding flight values.

G. Blade Shear Loads

1. Normal Shear

See curves of Section 4.

2. Chordwise Shear just Outboard of Blade Strap Fittings

(a) Cruise Condition	100 ± 260 lb. limit
(b) Weighted Fatigue Condition	200 ± 385 lb. limit
(c) 2-1/2g Maneuver Condition	100 ± 1550 lb. limit

Note: (1) Positive loads are up and aft on hub.

(2) Normal shears ~~do~~ <u>do not</u> include control forces.

H. Blade Bending Moments

1. Chordwise

Cruise at 100 knots	± 41,050 ip limit
Weighted fatigue	± 82,100 ip limit
2-1/2g Maneuver	± 253,000 ip limit
Over-Rev	No significant bending stresses

Note: Chordwise moments are given in a plane described by the blade feathering and flapping axes, with blade coned.

2. Normal Bending Moments

See Curves of Section 4.

I. Duct Operating Pressure and Temperature

1. 910 hours of life:

a. Desired	1117°F	26.9 psig
b. Minimum	1039°F	23.6 psig

2. 90 hours of life:

a. Desired	1184°F	29.0 psig
b. Minimum	1117°F	26.9 psig

3. Power off, rotor rotating:	800°F	-4.0 psig

Note: 1. The figures shown as desired must be used for design except in those cases where a severe cost or time penalty results. In such a case, the minimum figures may be used provided a later simple change (such as material substitution) will permit operation at the higher values.

J. Hub In-Plane Loads

1. Weighted Fatigue Condition

Use a 1.0g thrust with the vector at 6° to the shaft and with the hub inclined 5° to the shaft, or same lateral component with 1.5g thrust.

2. 2.5g Maneuver (ultimate condition)

Use a 2.5g thrust with the vector at 10° to the shaft and with the hub inclined 8° to the shaft.

K. FAA Factors — 1.15 fitting factor, 1.25 casting factor, etc., need not be applied.

1.5 RELATIVE MOVEMENTS; BLADE, HUB AND CONTROLS

Note: (1) Cyclic Pitch is defined as $\Theta_{1_s} \sin\psi + \Theta_{2_s} \cos\psi$, where ψ = blade azimuth location measured from the blade aft position, and Θ_{1_s} and Θ_{2_s} are measured with respect to the neutral swashplate position.

(2) Under dynamic transient conditions, hub lag relative to the swashplate may be as much as 2.88° beyond the steady state tilt. It will be restricted to this value by hydraulic flow restriction. (See note g, page 1.4.2.

A. Hub Tilt and Blade Coning, Flapping and Feathering Angles.

1. Clearance Cond.

Hub Tilt - relative to mast:

a.	at normal r.p.m.	10° in all azimuth positions
b.	at zero r.p.m.	2° in all azimuth positions

Blade Coning - relative to hub	15° up, 2° down
Blade Collective Pitch at 3/4 Radius	0° to 12°
Blade Cyclic Pitch - relative to mast	$\Theta_{1_s} = \pm 10^{\circ}$, $\Theta_{2_s} = \pm 7^{\circ}$

2. Level Flight, 100 knot Cruise

Hub Tilt - relative to mast	0° to 3° aft
Blade Coning - relative to hub	4.0°
Blade Flapping - relative to hub	$\pm 0.25^{\circ}$ at 2/rev

Blade Collective Pitch at 3/4 Radius	$+7.6^{o}$
Blade Cyclic Pitch - relative to hub	$\Theta_1 = 0^{o}$ to -3.8^{o}, $\Theta_2 = 1.7^{o}$
Blade Cyclic Pitch - relative to mast	$\Theta_{1_s} = 0^{o}$ to -0.8^{o}, $\Theta_{2_s} = 1.7^{o}$

3. 2.5g Maneuver Condition at 100 knots. (This condition is a dynamic maneuver; therefore, its description is presented in three parts.)

(a) Cyclic Stick Pull-Back

Helicopter Load Factor	1.0g
Hub Tilt - relative to mast	10^{o} aft
Blade Coning - relative to hub	$+4.0^{o}$
Blade Flapping - relative to hub	$\pm 0.25^{o}$ at 2/rev
Blade Collective Pitch at 3/4 Radius	$+7.6^{o}$
Blade Cyclic Pitch - relative to hub	$\Theta_1 = -3.8^{o}$, $\Theta_2 = +1.7^{o}$
Blade Cyclic Pitch - relative to mast	$\Theta_{1_s} = +6.2^{o}$, $\Theta_{2_s} = +1.7^{o}$

(b) Application of Full Collective Pitch and Decrease in Feathering Angle

Helicopter Load Factor	2.5g
Hub Tilt - relative to mast	10^{o} aft
Blade Coning - relative to hub	$+10^{o}$

Blade Flapping - relative to hub	$\pm 0.6^{\circ}$ at 2/rev
Collective Pitch at 3/4 R	12°
Blade Cyclic Pitch - relative to hub	$\Theta_1 = -9.5^{\circ}$, $\Theta_2 = +4.25^{\circ}$
Blade Cyclic Pitch - relative to mast	$\Theta_{1_s} = +0.5^{\circ}$, $\Theta_{2_s} = +4.25^{\circ}$

(c) Recovery (Cyclic pitch stick moved an additional 2.88°* forward)

Helicopter Load Factor	2.5g
Hub Tilt - relative to mast	10° aft*
Blade Coning - relative to hub	$+10^{\circ}$
Blade Flapping - relative to hub	$\pm 0.6^{\circ}$ at 2/rev
Blade Collective Pitch at 3/4 Radius	$+12^{\circ}$
Blade Cyclic Pitch - relative to hub	$\Theta_1 = -12.38^{\circ}$*, $\Theta_2 = +4.25^{\circ}$
Blade Cyclic Pitch - relative to mast	$\Theta_{1_s} = -2.38^{\circ}$*, $\Theta_{2_s} = +4.25^{\circ}$

* See Note (2) page 1.5.1

4. Weighted Fatigue Condition

Hub Tilt - relative to mast	0° to 6° aft
Blade Coning - relative to hub	$+4^\circ$ to $+8.0^\circ$, whichever is critical
Blade Flapping - relative to hub	$\pm 0.5^\circ$ at 2/rev
Blade Collective Pitch - at 3/4 Radius	$+7.6^\circ$
Blade Cyclic Pitch - relative to hub	$\Theta_1 = 7.6^\circ$, $\Theta_2 = +3.4^\circ$
Blade Cyclic Pitch - relative to mast	$\Theta_{1_s} = 1.6^\circ$, $\Theta_{2_s} = +3.4^\circ$

5. Entry into Autorotation from Cruise

Hub Tilt - relative to mast	3° aft
Blade Coning - relative to hub	$+4^\circ$
Blade Flapping - relative to hub	$\pm 0.25^\circ$ at 2/rev
Blade Collective Pitch at 3/4 Radius	0°
Blade Cyclic Pitch - relative to hub	$\Theta_1 = 6.68^\circ$, $\Theta_2 = +1.7^\circ$
Blade Cyclic Pitch - relative to mast	$\Theta_{1_s} = 3.68^\circ$, $\Theta_{2_s} = +1.7^\circ$

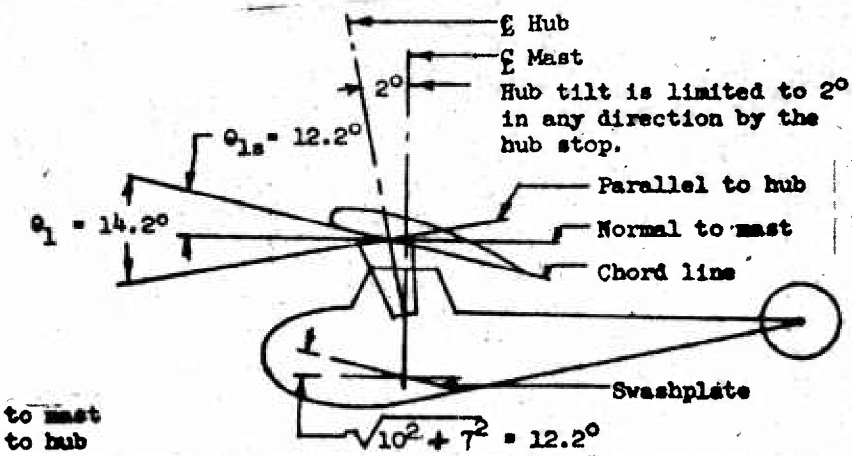
6. 2.5g Autorotation Maneuver at 100 knots (flareout)

Helicopter Load Factor	2.5g
Hub Tilt - relative to mast	10° aft
Blade Coning - relative to hub	$+10^{\circ}$
Blade Flapping - relative to hub	$\pm 0.6^{\circ}$ at 2/rev
Blade Collective Pitch at 3/4 Radius	$+3^{\circ}$
Blade Cyclic Pitch - relative to hub	$\Theta_1 = -11.5^{\circ}$, $\Theta_2 = 0^{\circ}$
Blade Cyclic Pitch - relative to mast	$\Theta_{1_s} = -1.5^{\circ}$, $\Theta_{2_s} = 0^{\circ}$

STRAP WINDUP

HUB AND ROTOR BLADE GROUND CLEARANCE CHECK

VIEW SHOWS AN ADVANCING BLADE AT APPROXIMATELY 135° AZIMUTH

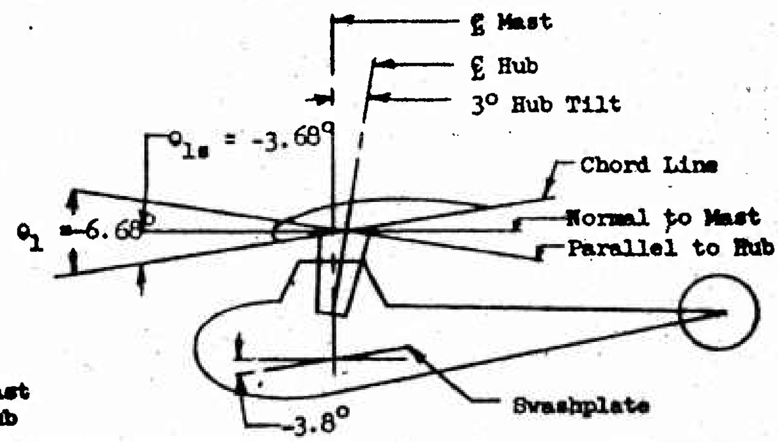


θ_{1s} = Pitch relative to mast
θ_1 = Pitch relative to hub

COLLECTIVE PITCH	MAX. STRAP WINDUP	
	ADVANCING BLADE	RETREATING BLADE
12°-7.6°=4.4° at pitch arm	+14.2° + 4.4° =+18.6° (Blade Nose Up)	-14.2° + 4.4° =-9.8° (Blade Nose Down)
0°-7.6°=-7.6° at pitch arm	+14.2° - 7.6° =+6.6° (Blade Nose Up)	-14.2° – 7.6° =-21.8° (Blade Nose Down)

ENTRY INTO AN AUTOROTATION MANEUVER FROM A CRUISE CONDITION

VIEW SHOWS AN ADVANCING BLADE AT 90° AZIMUTH



θ_{1s} = Pitch relative to mast
θ_1 = Pitch relative to hub

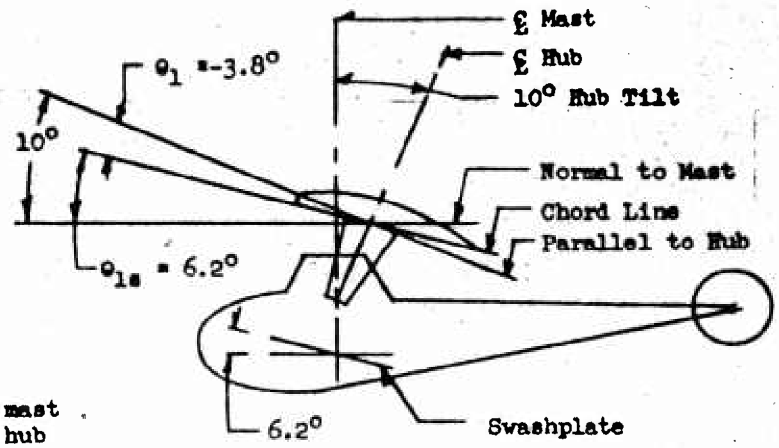
COLLECTIVE PITCH	MAX. STRAP WINDUP	
	ADVANCING BLADE	RETREATING BLADE
0°-7.6°= -7.6° at pitch arm	-6.68 - 7.6° = -14.28° (Blade Nose Down)	+6.68°-7.6° = -0.92° (Blade Nose Down)

STRAP WINDUP

2.5G MANEUVER CONDITION AT 100 KNOTS

STEP I - CYCLIC STICK PULL BACK

VIEW SHOWS AN ADVANCING BLADE AT 90° AZIMUTH



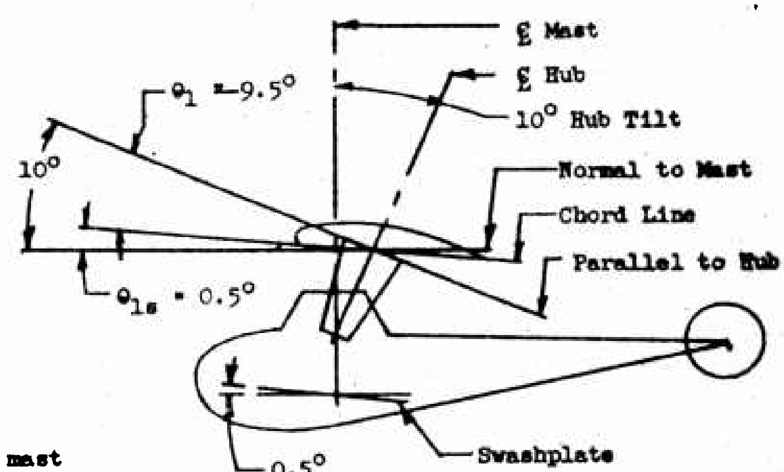
θ_{1s} = Pitch relative to mast
θ_1 = Pitch relative to hub

COLLECTIVE PITCH	MAXIMUM STRAP WINDUP	
	ADVANCING BLADE	RETREATING BLADE
7.6°-7.6°=0° at Pitch Arm	-3.8° (Blade Nose Down)	+ 3.8° (Blade Nose Up)

2.5G MANEUVER CONDITION AT 100 KNOTS

STEP 2 - APPLICATION OF FULL COLLECTIVE PITCH

VIEW SHOWS AN ADVANCING BLADE AT 90° AZIMUTH



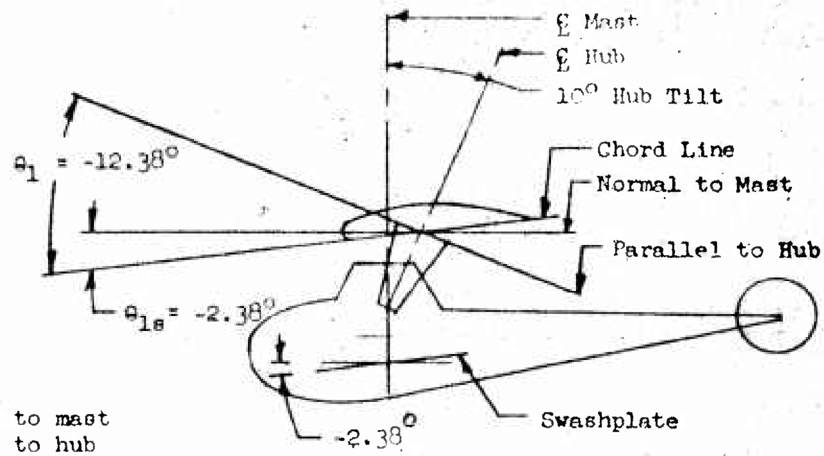
θ_{1s} = Pitch relative to mast
θ_1 = Pitch relative to hub

COLLECTIVE PITCH	MAXIMUM STRAP WINDUP	
	ADVANCING BLADE	RETREATING BLADE
12°-7.6°=4.4° at pitch arm	-9.5° + 4.4° =-5.1° (Blade Nose Down)	+9.5°+ 4.4° =+13.9° (Blade Nose Up)

2.5G MANEUVER CONDITION AT 100 KNOTS

STEP 3 - RECOVERY PORTION

VIEW SHOWS AN ADVANCING BLADE AT 90° AZIMUTH

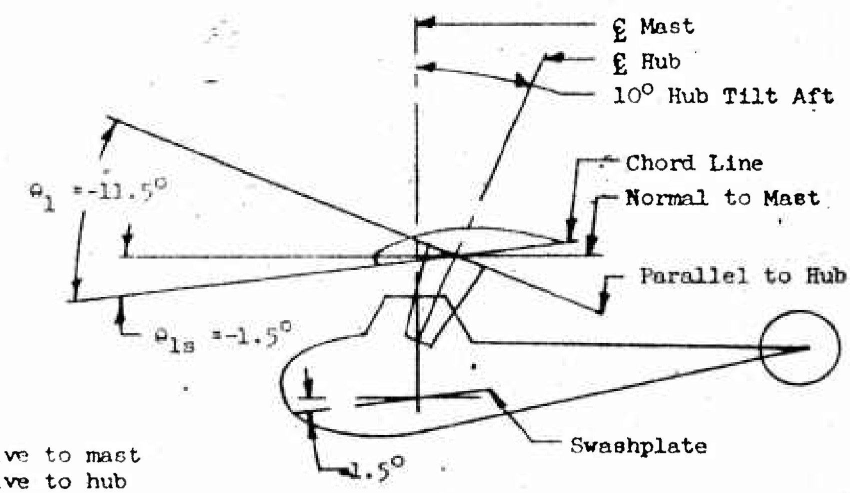


θ_{1s} = Pitch relative to mast
θ_1 = Pitch relative to hub

COLLECTIVE PITCH	MAXIMUM STRAP WINDUP	
	ADVANCING BLADE	RETREATING BLADE
12° - 7.6° = 4.4° at pitch arm	-12.38° + 4.4° = -7.98° (Blade Nose Down)	+12.38° + 4.4° = +16.78° (Blade Nose Up)

2.5G AUTOROTATION MANEUVER AT 100 KNOTS
"FLAREOUT"

VIEW SHOWS AN ADVANCING BLADE AT 90° AZIMUTH



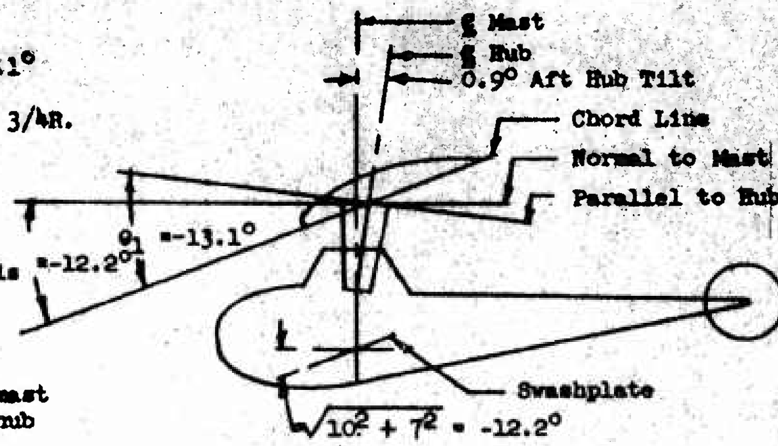
θ_{1s} = Pitch relative to mast
θ_1 = Pitch relative to hub

COLLECTIVE PITCH	MAXIMUM STRAP WINDUP	
	ADVANCING BLADE	RETREATING BLADE
3° - 7.6° = - 4.6° at pitch arm	-11.5° - 4.6° = -16.1° (Blade Nose Down)	+11.5° - 4.6° = +6.9° (Blade Nose Up)

IDLING CONDITION - HUB TILT AFT

Hub Tilt Aft; to follow swashplate but may lag* by 13.1°
cyclic pitch - 12.2°
collective pitch 0° to 12° at 3/4R.

VIEW SHOWS AN ADVANCING BLADE AT APPROXIMATELY 135° AZIMUTH



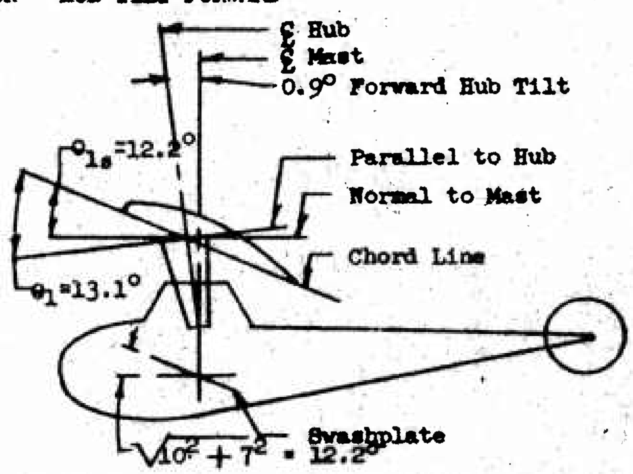
θ_{1s} = Pitch relative to mast
θ_1 = Pitch relative to hub

COLLECTIVE PITCH	MAXIMUM STRAP WINDUP	
	ADVANCING BLADE	RETREATING BLADE
0° - 7.6° = -7.6° at pitch arm	-13.1°-7.6° = -20.7° (Blade Nose Down)	+13.1°-7.6° = +5.5° (Blade Nose Up)
12°-7.6° = + 4.4° at pitch arm	-13.1°+ 4.4° = -8.7° (Blade Nose Down)	+ 13.1°+ 4.4° = +17.5° (Blade Nose Up)

IDLING CONDITION - HUB TILT FORWARD

Hub Tilt Forward; to follow swashplate but may lag* by 13.1°.
cyclic pitch + 12.2°
collective pitch 0° to 12° at 3/4R.

VIEW SHOWS AN ADVANCING BLADE AT APPROXIMATELY 135° AZIMUTH



θ_{1s} = Pitch relative to mast
θ_1 = Pitch relative to hub

COLLECTIVE PITCH	MAXIMUM STRAP WINDUP	
	ADVANCING BLADE	RETREATING BLADE
0° - 7.6° = -7.6° at pitch arm	+ 13.1° -7.6° = + 5.5° (Blade Nose Up)	-13.1° -7.6° = -20.7° (Blade Nose Down)
12° - 7.6° = + 4.4° at pitch arm	+ 13.1° + 4.4° = +17.5° (Blade Nose Up)	-13.1° + 4.4° = -8.7° (Blade Nose Down)

*Hub Lag = $2.88° \times \frac{\text{Normal RPM}}{\text{Idle RPM}} = 2.88° \times \frac{243}{53.5} = 13.1°$

Date: 25 November 1959

1.6 CALCULATED OPERATING TEMPERATURES OF STRUCTURAL AND MECHANICAL COMPONENTS

This section contains the operating temperatures used in the design of the Hot Cycle Rotor. Temperatures given on the following pages are based on the thermal analysis of Report 285-10. The Temperature Location Chart on the following page locates by number all critical components. Following the chart the components are listed and temperatures are given along with a statement of the local conditions. All component temperatures are based on a gas temperature of 1200°F. at an ambient air temperature of 100°F. Recently obtained temperature data measured during the whirl test show that the predicted temperatures are moderately conservative for most components.

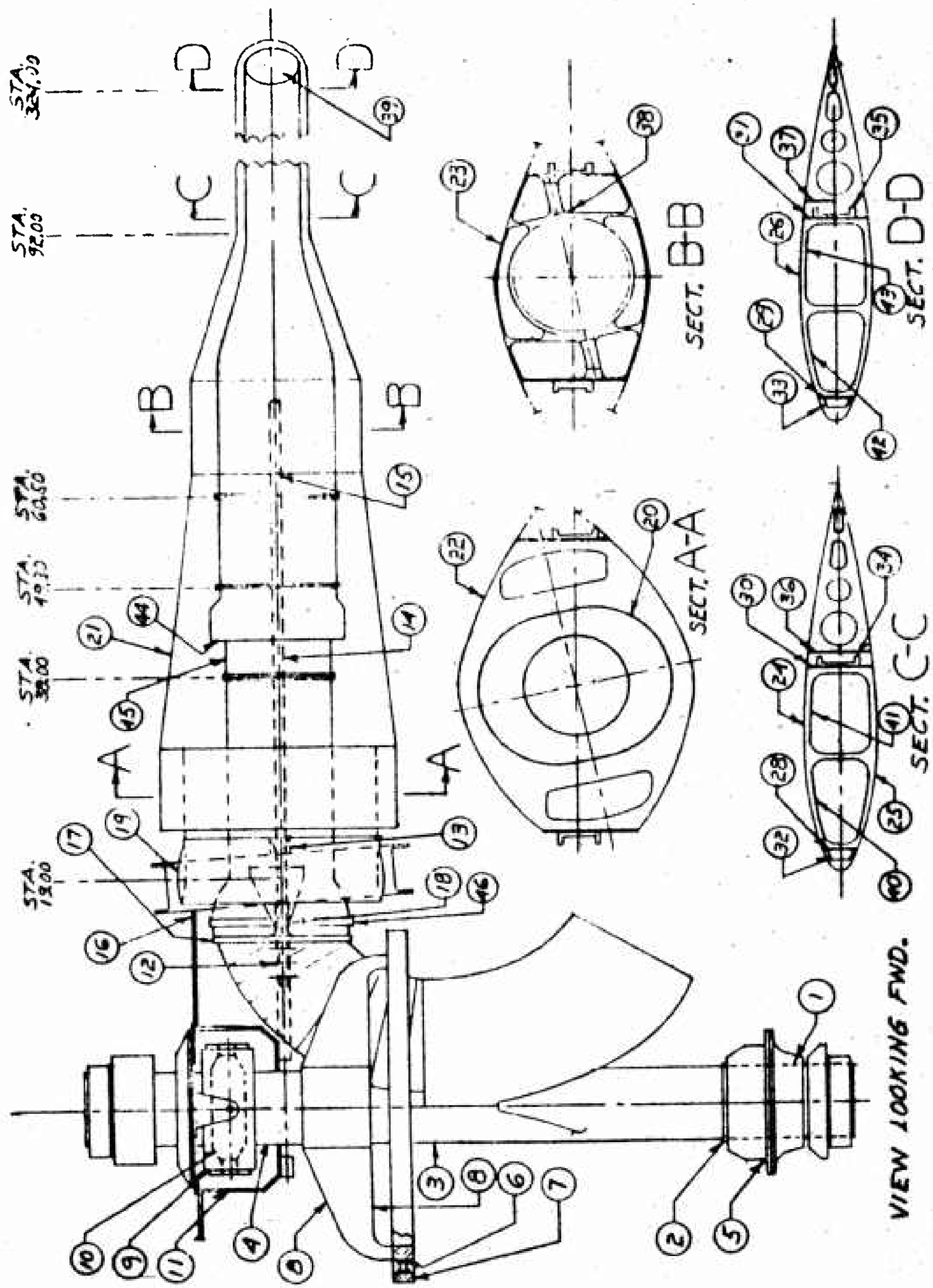


Figure 1-1. Temperature Location Chart

General Conditions:

Reference: Hot Cycle Thermal Analysis, Report 285-10

Duct Temperature	1200°F
Ambient Air Temperature	100°F
Altitude	Sea Level

Duct surfaces and/or shielding, unless otherwise noted:

a.	Blade constant section	Ducts bare; shield of cres, aluminum coated
b.	Blade root and hub	Duct thermal resistance equal to an emissivity of 0.04

A general relationship for correcting the temperatures given in this summary to equivalent values at other operating gas temperatures is:

$$T_x = 100 + \frac{(T_{gas} - 100)}{1100} (T_{ox} - 100)$$

where:

T_x = location temperature at new gas temperature

T_{gas} = new gas temperature

T_{ox} = location temperature at 1200°F gas temperature

This relationship assumes all material properties remain constant with changes in temperature, which is sufficiently accurate over a limited range of temperatures (approx ± 300°F).

Location No.	Name of Component	Local Conditions	Temp. (°F)
1	Mast at thrust bearing lower region	Steel Mast, Cad Plated. An Aliron shield with 1/4 in. air gap is required over the upper surface of the bearing. No shield should be used on the lower surface which would interfere with the natural convection cooling.	150°

Location No.	Name of Component	Local Conditions	Temp. (°F)
2	Mast just above thrust bearing	Steel Mast, Cad Plated	370° without shield. 160° if 1/4 air gap Aliron shield applied to mast.
3	Mast 16.00 below tilt axis	Steel Mast, Cad Plated. Aliron shields with 1/4 air gap are required on the duct above and below the seal. A shield should be also included between the seal and the mast to deflect leakage air away from the mast.	Av. 360° Max. 500°, under the titanium spacers
4	Mast just below rotor gimbal	Steel Mast, Cad Plated. No shielding is required on the mast. The 1/4 in. gap Aliron shield is required on the duct.	250°
5	Thrust bearing housing	Alum. Alloy Housing, Anodized. Shield as specified in Location 1.	240°
6	Inner (stationary) support ring for radial bearing	Steel Ring, Cad Plated Air gap noted for Location 7.	150°
7	Outer (rotating) support ring for radial bearing	Steel Ring, Cad Plated 0.2 inch gap between ring and air seal.	140°
8	Bottom and Top of Spokes	Steel Spokes, Cad Plated. A thermal conductivity of 0.4 Btu/hr - ft - F was assumed for the insulation block. About 20 percent of the heat is conducted through the .08 inch titanium foil around the block.	590° above the support blocks 400° at the shaft

Location No.	Name of Component	Local Conditions	Temp. (°F)
9	Rotor Gimbal Ring	Alum. Alloy Gimbal, Anodized	170°
10	Rotor Gimbal Trunion	Alum. Alloy Gimbal, Anodized	175°
11	Tilting Hub Inner Ring	Steel Ring, Cad Plated	200°
12	Hub Strap Attach Plates at Center Strap Bolt	Steel Plates, Cad Pladed. Aliron Sheild over duct only	250°
13	Blade Strap at Inboard Fitting	Cor. Res. Stl, Bare	250°
14	Blade Strap at Sta. 40	Cor. Res. Stl, Bare	160°
15	Blade Strap at Outboard Shoe Tangent Point	Cor. Res. Stl, Bare	260°
16	Floating Hub Inboard of Flapping-Feathering Bearing	Steel, Cad Plated	120°
17	Articulate Duct Gimbal Ring	Steel, Nickel Plated Cooling air circulated inside a radiation shield	200° without leakage 270° with 1% leakage
18	Articulated Duct Gimbal Bearing	Cor. Res. Steel Bracket, bare	350°
19	Flapping-Feathering Bearing Ball	Alum. Alloy Ball	400°
20	Blade Inner Surface Sta. 28	Alum. Alloy, Alclad	215°

Location No.	Name of Component	Local Conditions	Temp. ($^{\circ}F$)
21	Blade Skin, Sta. 33 to 63	Alum. Alloy, Alclad	280°
22	Blade Skin at Sta. 28	Alum. Alloy, Alclad	140°
23	Blade Skin at Sta. 73	Alum. Alloy, Alclad	215°
24	Blade Upper Skin at Sta. 92	Cor. Res. Steel, Bare	Figure 1-3 Page 1.6.10
25	Blade Lower Skin Sta. 92	Cor. Res. Steel, Bare	Figure 1-4 Page 1.6.11
26	Blade Upper Skin * Sta. 210	Cor. Res. Steel, Bare	Figure 1-5 Page 1.6.12
27	Blade Upper Skin * Sta. 330	Cor. Res. Steel, Bare	Figure 1-6 Page 1.6.13
28	Blade Fwd. Segment Fwd. Web at Sta. 92	Cor. Res. Steel, Bare	414°
29	Blade Fwd. Segment Fwd. Web at Sta. 324	Cor. Res. Steel, Bare	470°
30	Blade Fwd. Segment Aft Web at Sta. 92	Cor. Res. Steel, Bare	317°
31	Blade Fwd. Segment Aft Web at Sta. 330	Cor. Res. Steel, Bare	441°
32	Blade Front Spar at Sta. 92	A layer of teflon between spar and fwd. segment web	394° Average

* Differential between top and bottom skin temperatures is small at this radius, less than 40°.

Location No.	Name of Component	Local Conditions	Temp. (^{o}F)
33	Blade Front Spar at Sta. 330	A layer of teflon between spar and fwd. segment web	460^{o} Average
34	Blade Rear Spar at Sta. 92	A layer of teflon between spar and fwd. segment web	310^{o} Average
35	Blade Rear Spar at Sta. 330	A layer of teflon between spar and fwd. segment web	435^{o} Average
36	Blade Aft Segment Fwd. Web at Sta. 92	Alum. Alloy web, Alclad	131^{o}
37	Blade Aft Segment Fwd. Web at Sta. 330	Alum. Alloy Web, Alclad	158^{o}
38	Blade Inner Web between ribs at Sta. 63 & 73 (temp at Sta. 73)	Alum. Alloy Web, Alclad	335^{o} (290^{o} for gas temp = 1040^{o})
39	Blade Tip Aft Fairing	Within an exhaust cone having an 11^{o} half angle	1110^{o}
40	Blade Fwd. Duct at Sta. 92	Rene' 41	Figs. 1-3 & 1-4 Pages 1.6.10, 11
41	Blade Aft Duct at Sta. 92	Rene' 41	Figs. 1-3 & 1-4 Pages 1.6.10, 11
42	Blade Fwd. Duct at Sta. 330	Rene' 41	Figure 1-6 Page 1.6.13
43	Blade Aft Duct at Sta. 330	Rene' 41	Figure 1-6 Page 1.6.13
44	Outboard Articulated Duct Seal Fitting, Sta. 42, (Dwg. 285-0182)	Cres, Type 347, bare	800^{o}

Location No.	Name of Component	Local Conditions	Temp. (^{O}F)
45	Duct Wall, Sta. 42	Cres, Type 347, bare	1170^{O}
46	Inboard Articulated Duct Seal Housing, Sta. 15.5	Cres, Type 17-4PH, bare, Aliron shield with cooling air circulated inside	550^{O} without leakage 950^{O} with 1% leakage

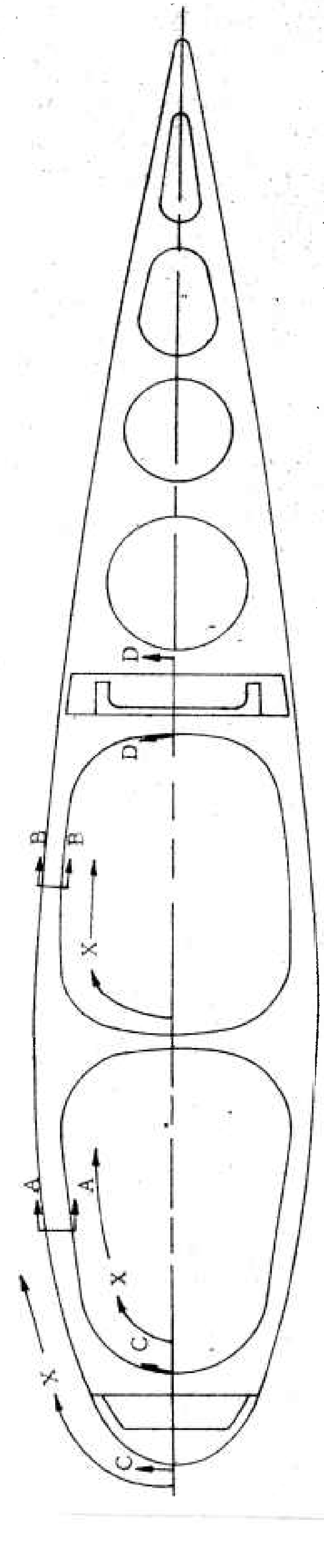


Figure 1-2. Locations for Cross-Sectional Temperature Gradients Blade Constant Section

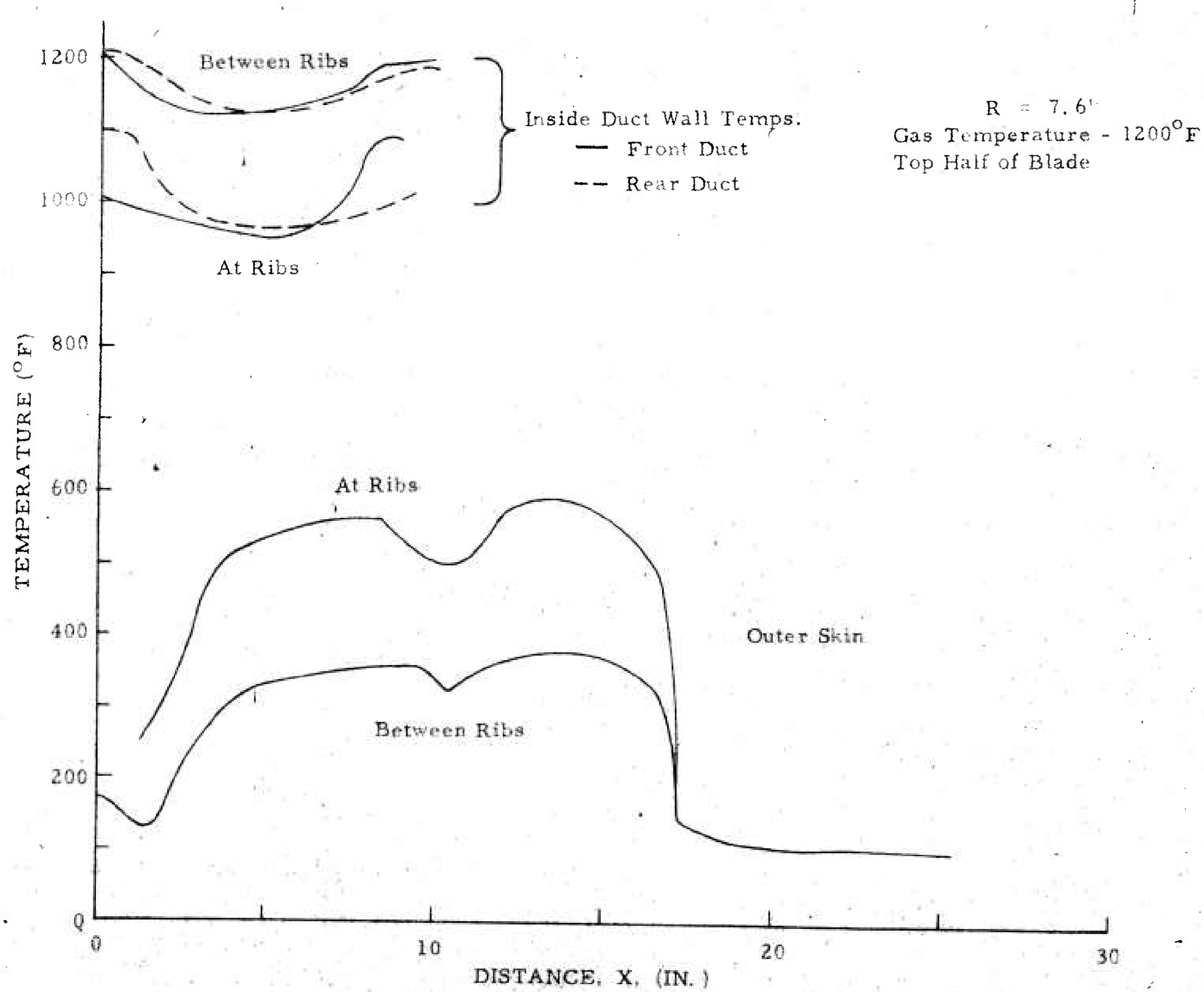


Figure 1-3. Hot Cycle Rotor Blade Temperatures at Steady State

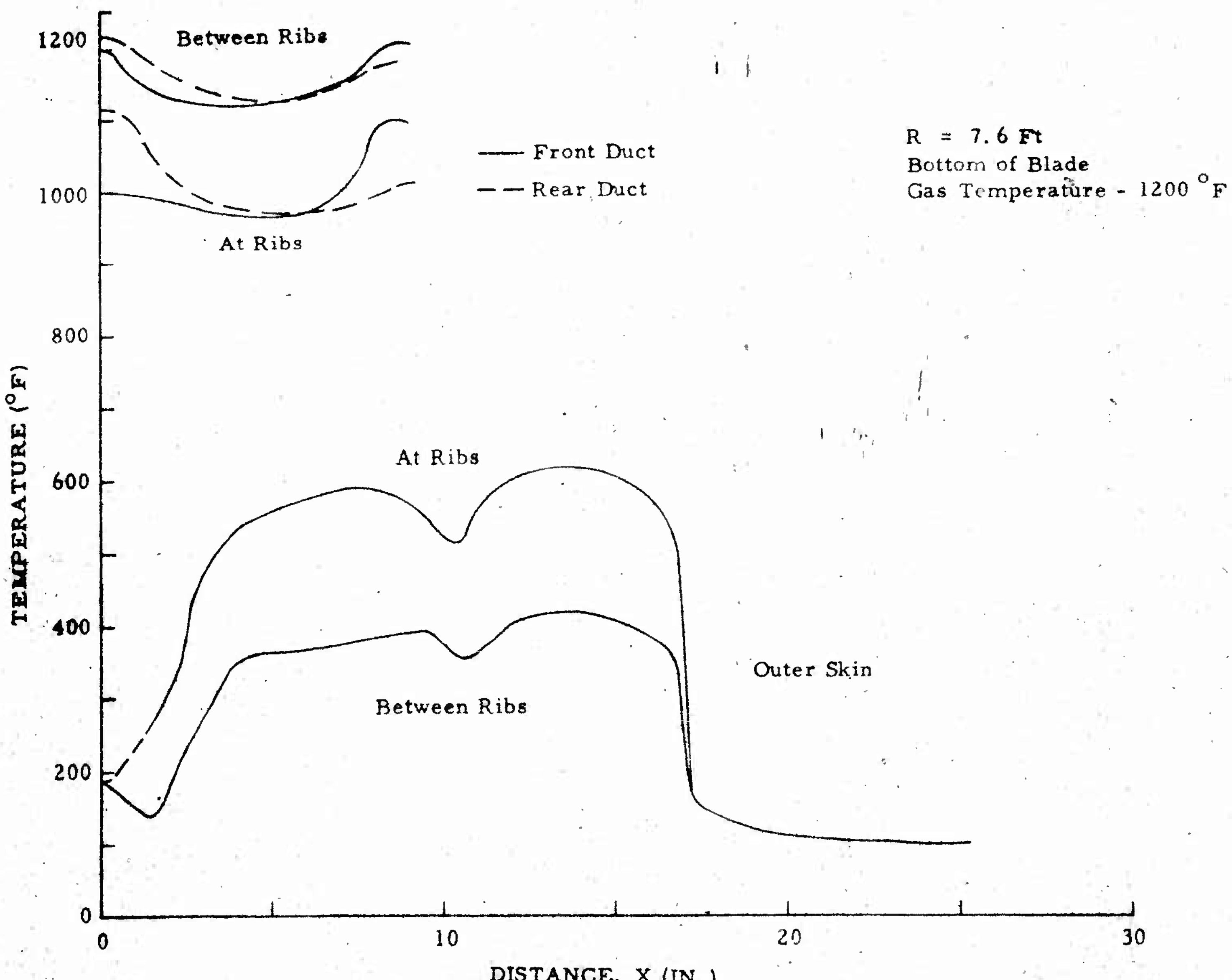


Figure 1-4. Hot Cycle Rotor Blade Temperatures at Steady State

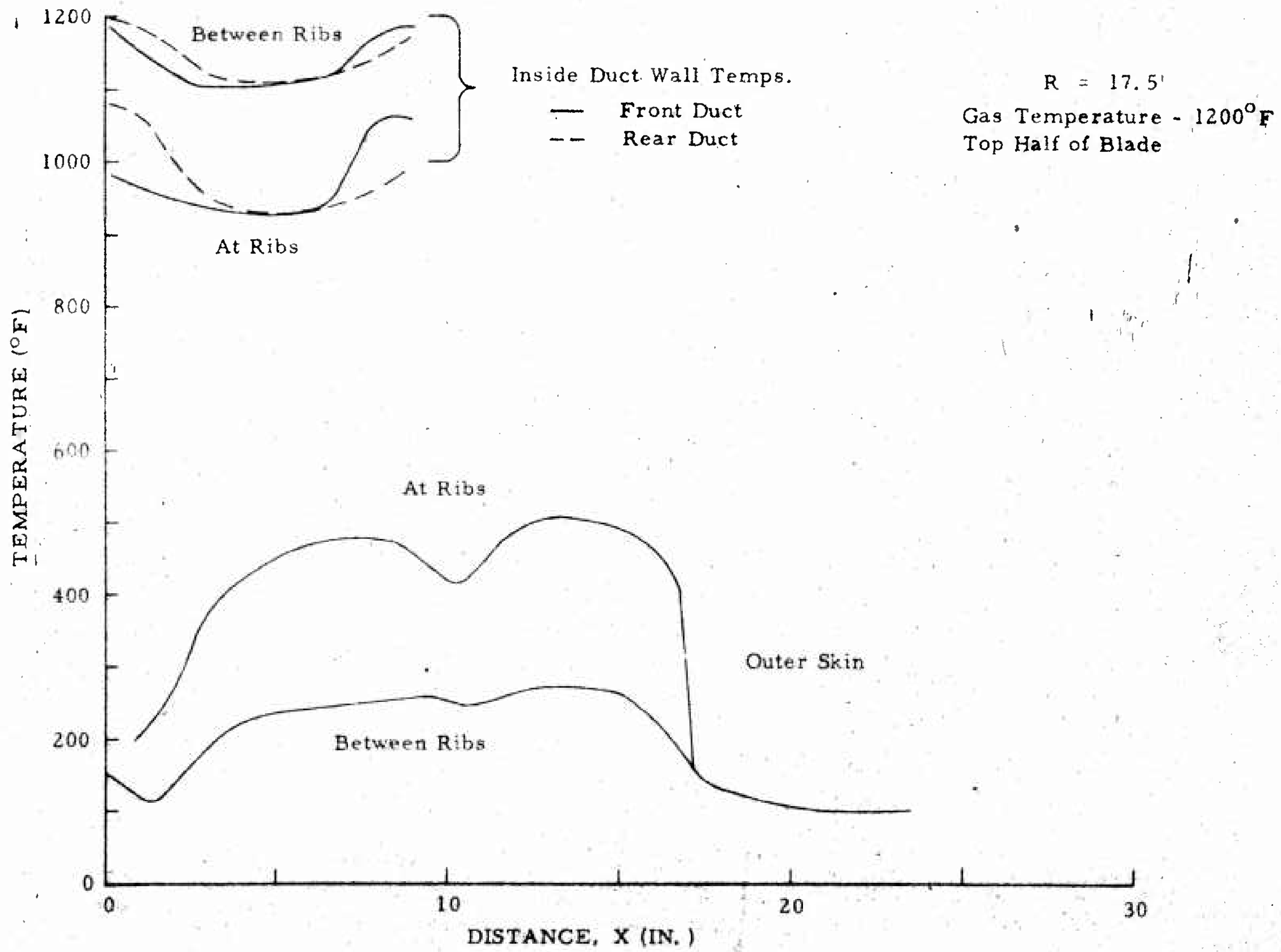


Figure 1-5. Hot Cycle Rotor Blade Temperatures at Steady State

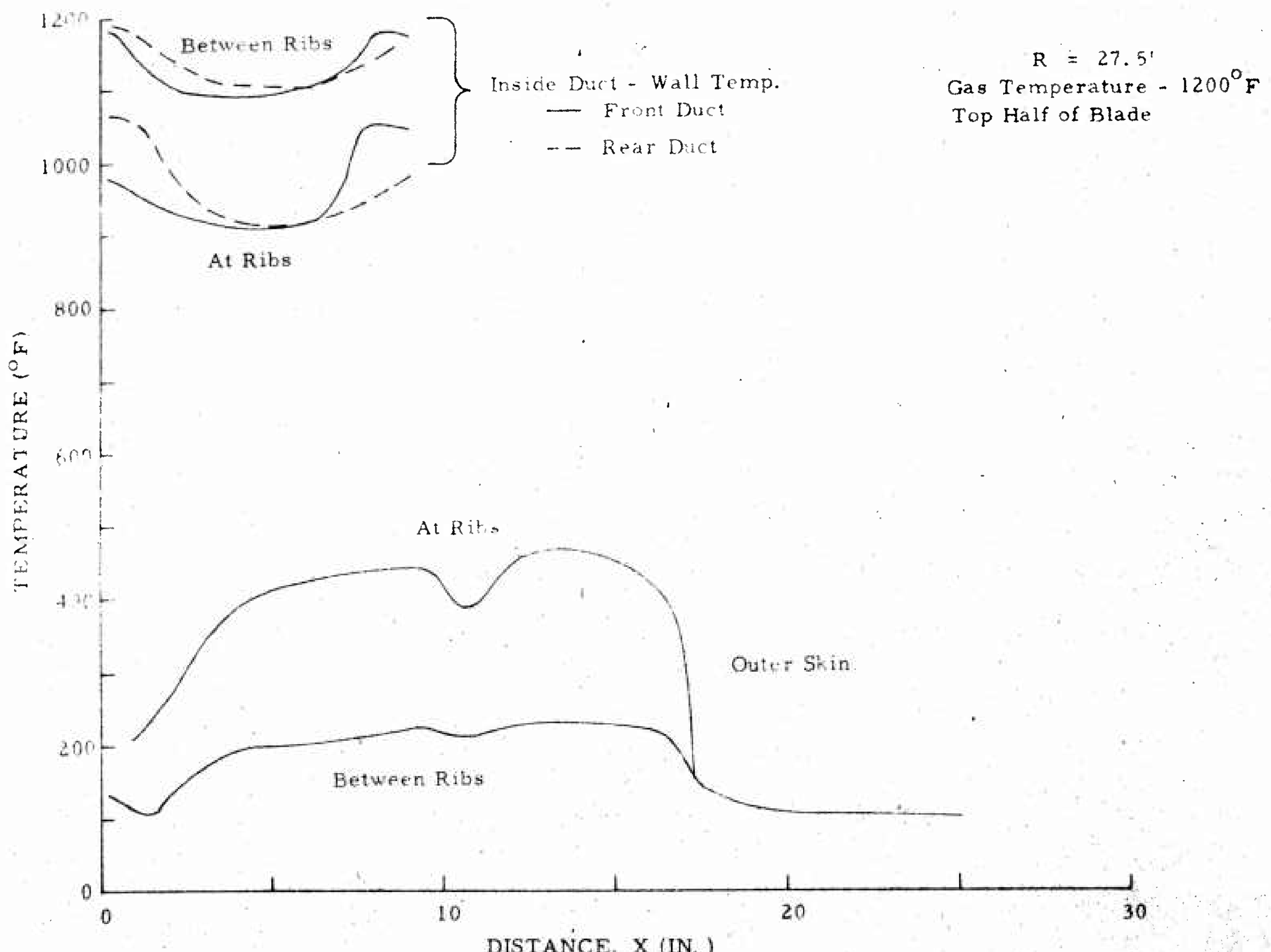


Figure 1-6. Hot Cycle Rotor Blade Temperature at Steady State

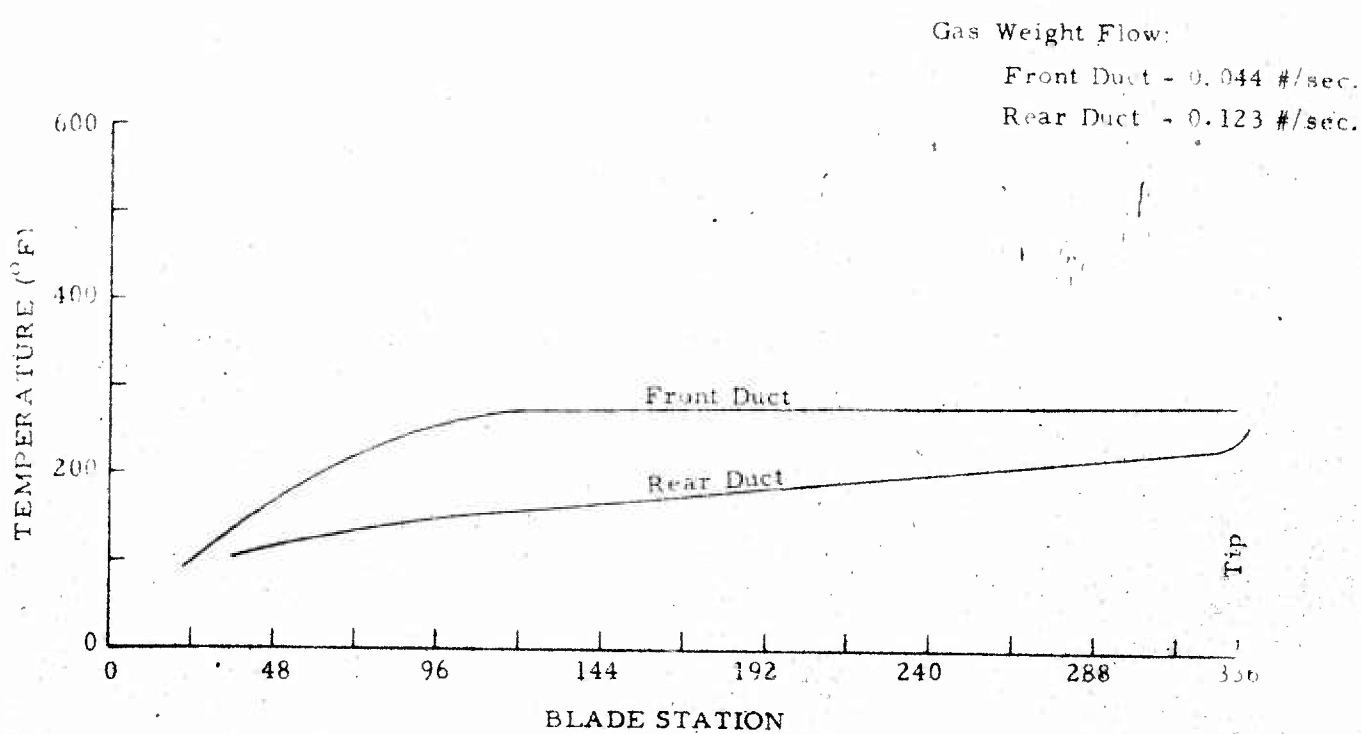


Figure 1-7. Cooling Duct Gas Temperature Vs. Distance Along Hot Cycle Rotor Blade

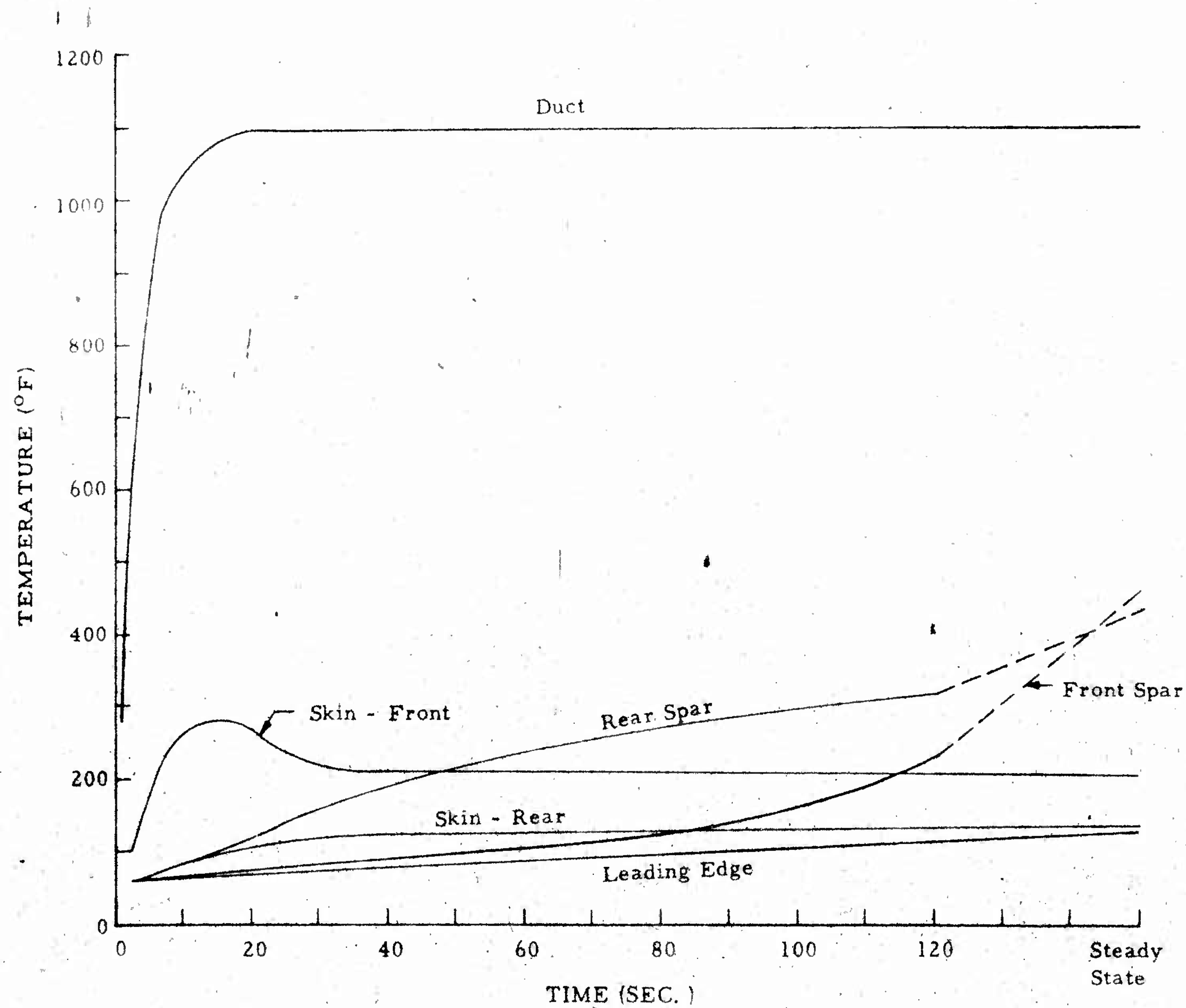


Figure 1-8. Temperature Vs. Time For Hot Cycle Rotor R = 27.5 Ft.

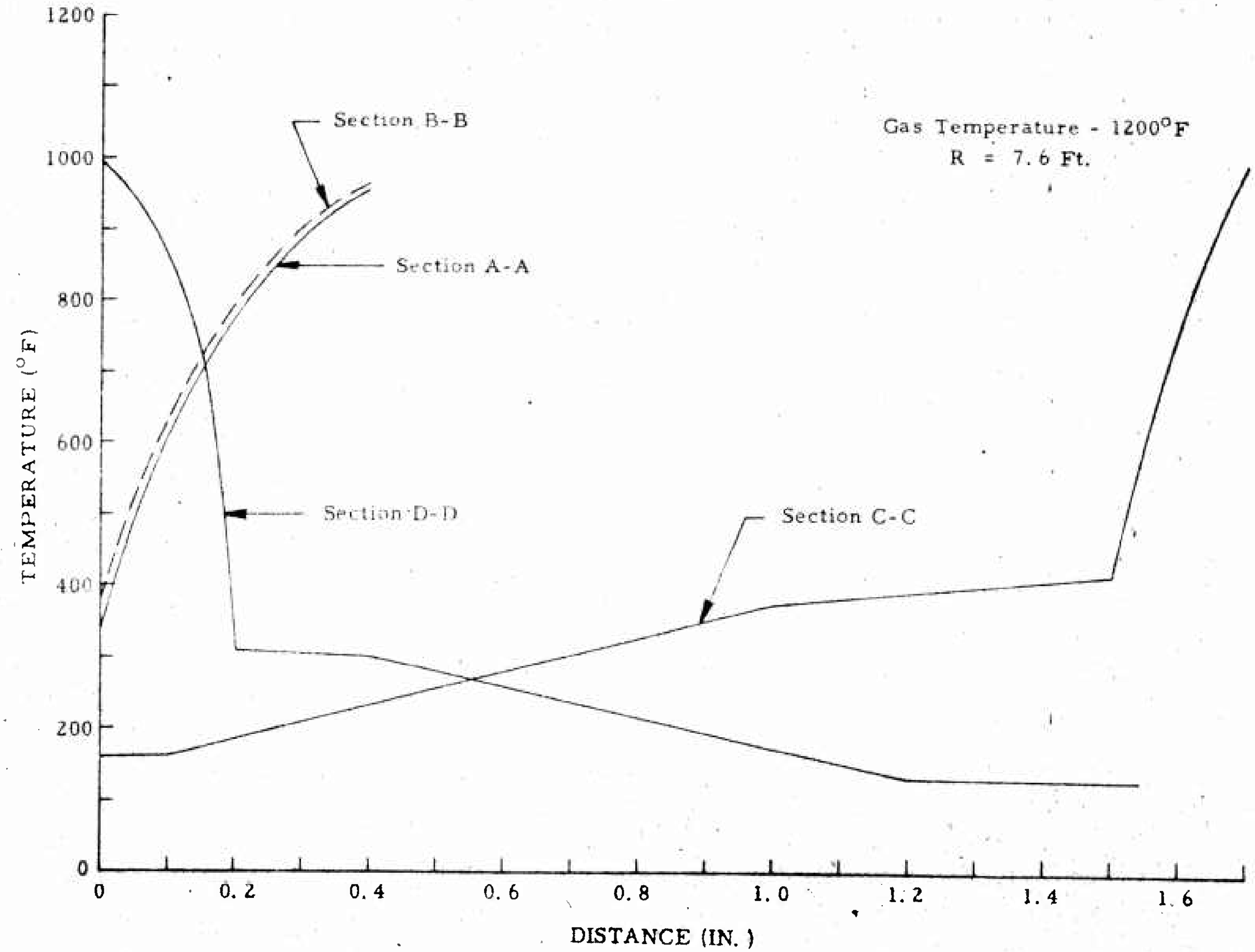


Figure 1-9. Cross-Sectional Temperature Gradients for Hot Cycle Rotor Blade (For Section Locations, See Figure 1-2)

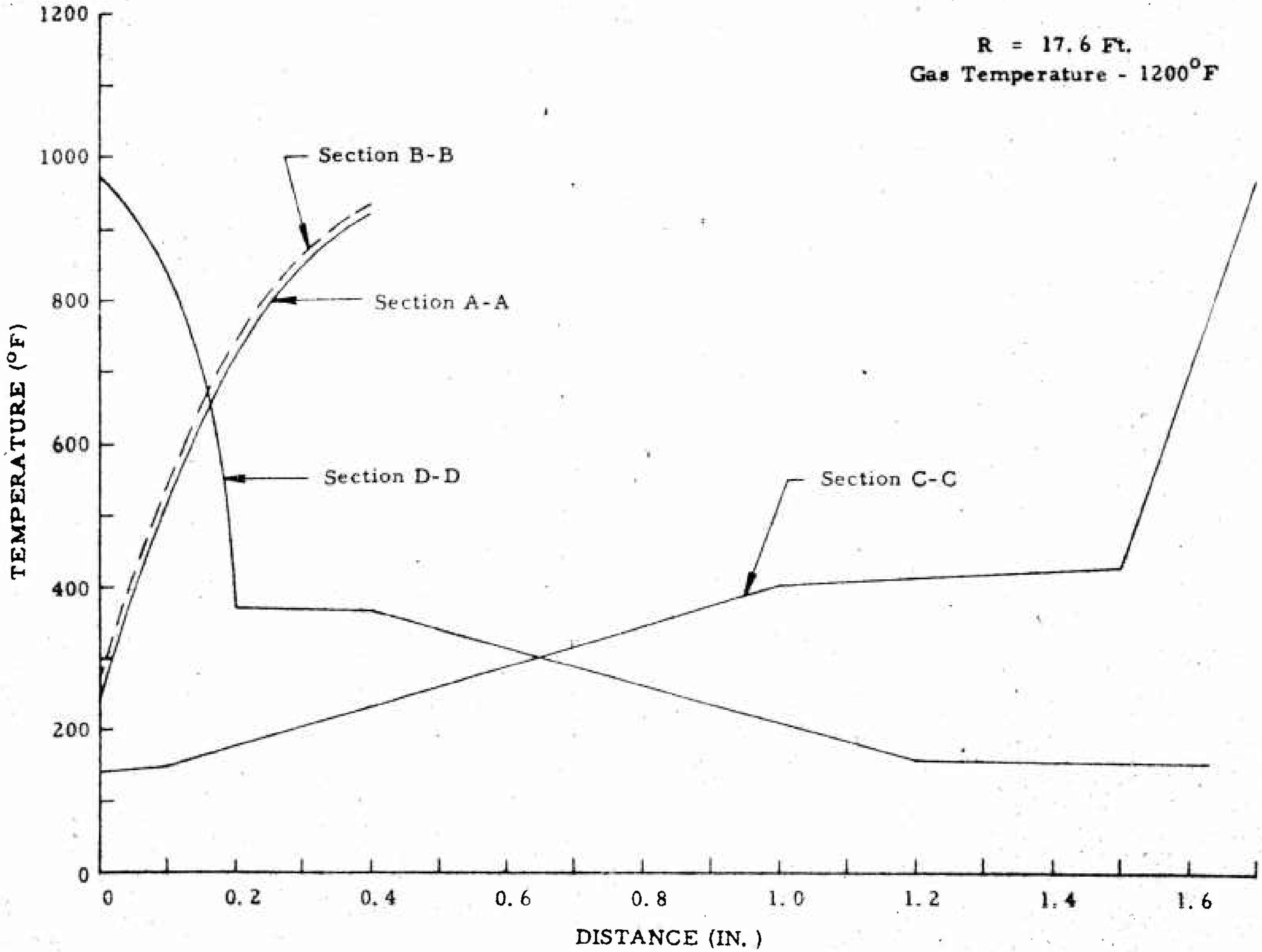


Figure 1-10. Cross-Sectional Temperature Gradients for Hot Cycle Rotor Blade (For Section Locations, See Figure 1-2)

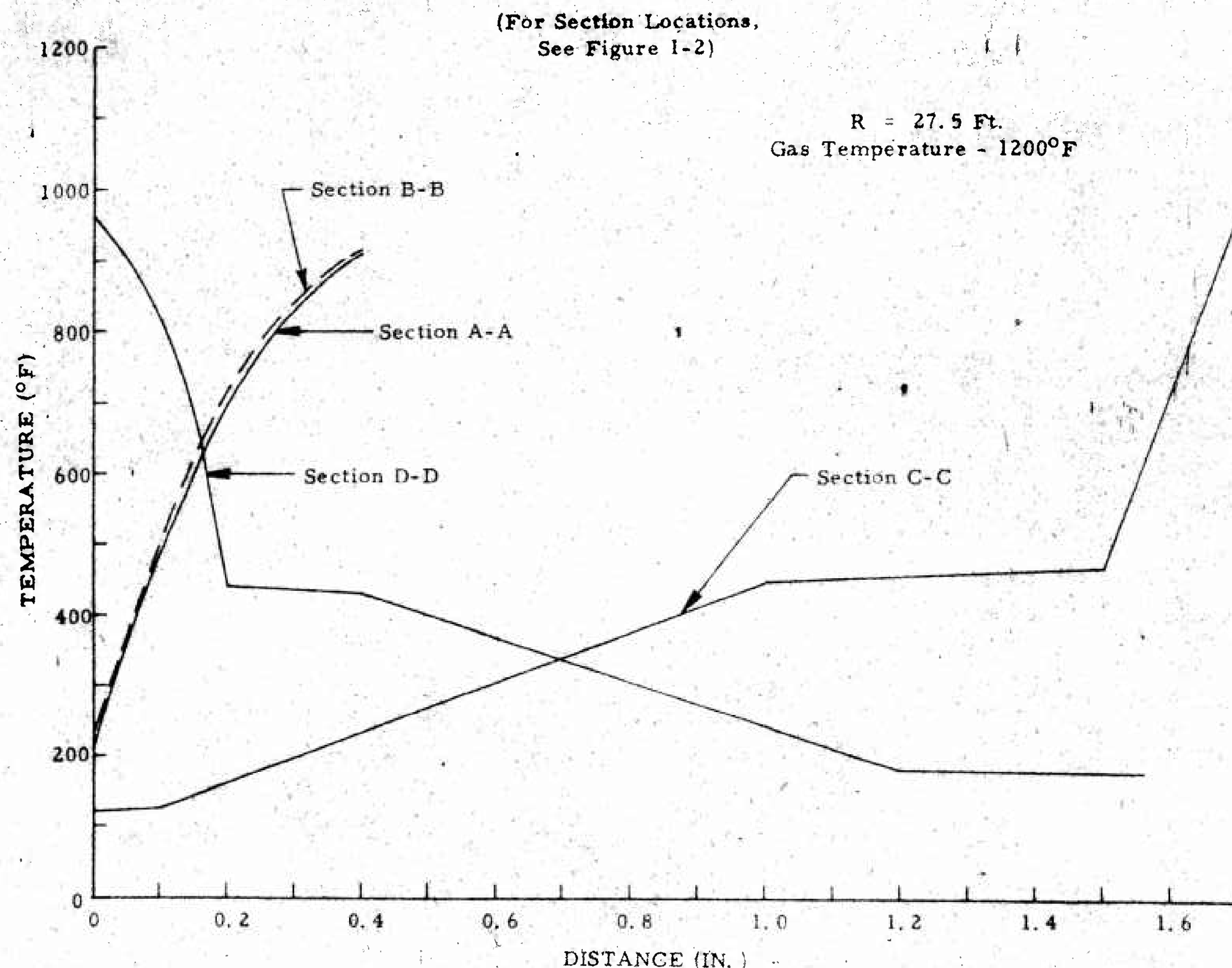


Figure 1-11. Cross-Sectional Temperature Gradients for Hot Cycle Rotor Blade
(For Section Locations, See Figure 1-11)

SECTION 2

MATERIAL SELECTION

CONTENTS

2.1 INTRODUCTION TO MATERIAL SELECTION

The design fabrication, and testing of the Hot Cycle Rotor System was to prove the practicability of using ducted hot exhaust gases as a means of rotor propulsion. Inasmuch as these gases were in the temperature range of 1050 to 1200°F, the material selection was extremely critical. The available material which would operate efficiently in this temperature range and still satisfy the required strength-weight relationship was limited. In addition, it was desirable to select materials which would, in so far as possible, lend themselves to fabrication by the various conventional forming and joining operations.

The reasons for selection of the basic structural materials are shown below, along with some of the chemical analyses and physical properties curves which were used as a basis for the designs.

2.2 RENE' 41 (NICKEL BASE ALLOY)

Basic Analyses

47%	Ni
20%	Cr
10%	Co
10%	Mo
3%	Ti
1-1/2%	Al

This alloy was utilized in the blade Duct-Rib Assemblies, and for the Lip Seals in view of its superior combination of yield, creep and tensile strength and its resistance to oxidation at elevated temperatures. In the temperature range of operation of the subject blades (1050 - 1200°F) it is one of the strongest of the alloys commercially available. Although some fabrication difficulties were expected above those normally encountered in general air frame construction, the Rene' 41 because of its superior properties, was selected.

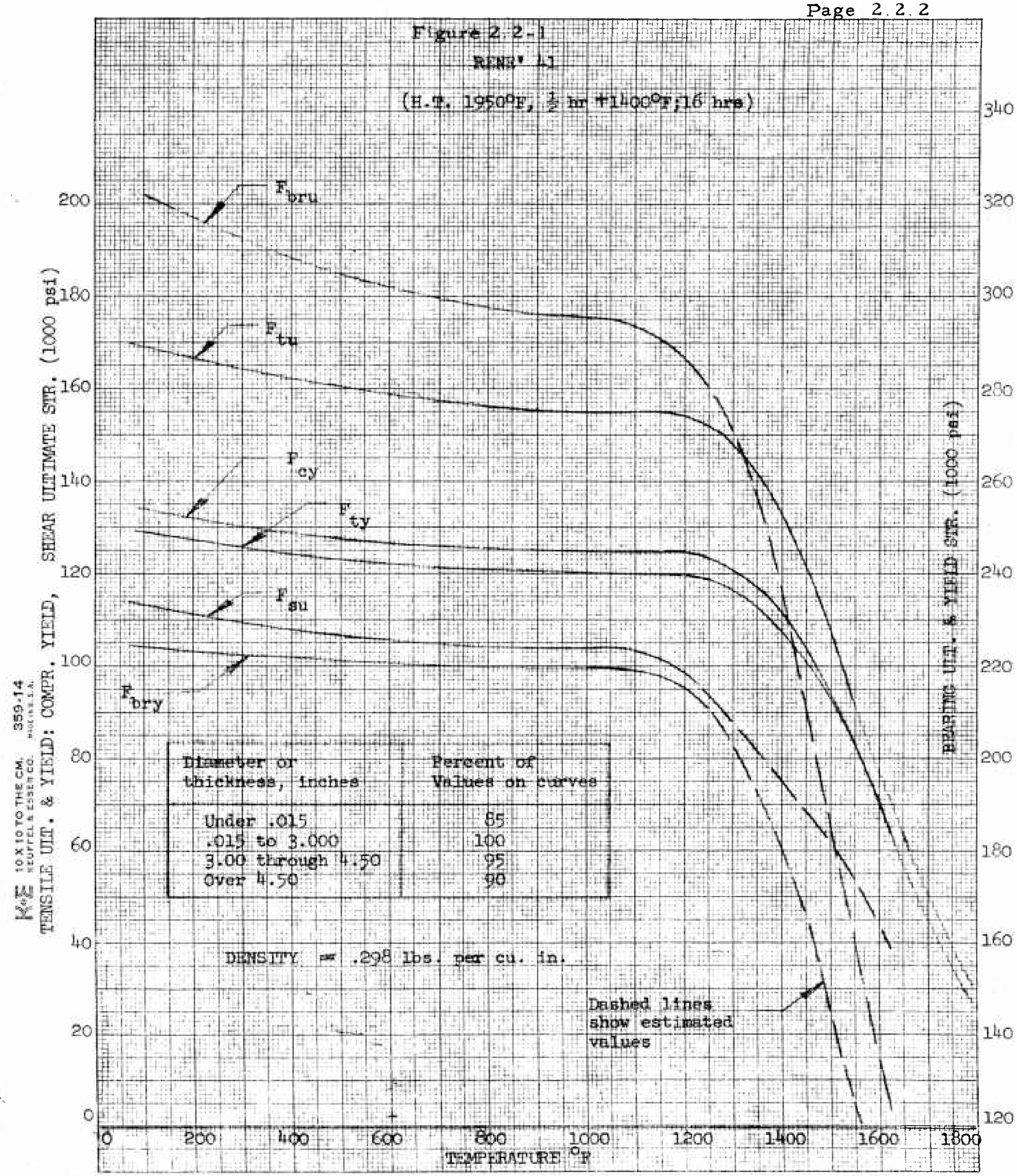


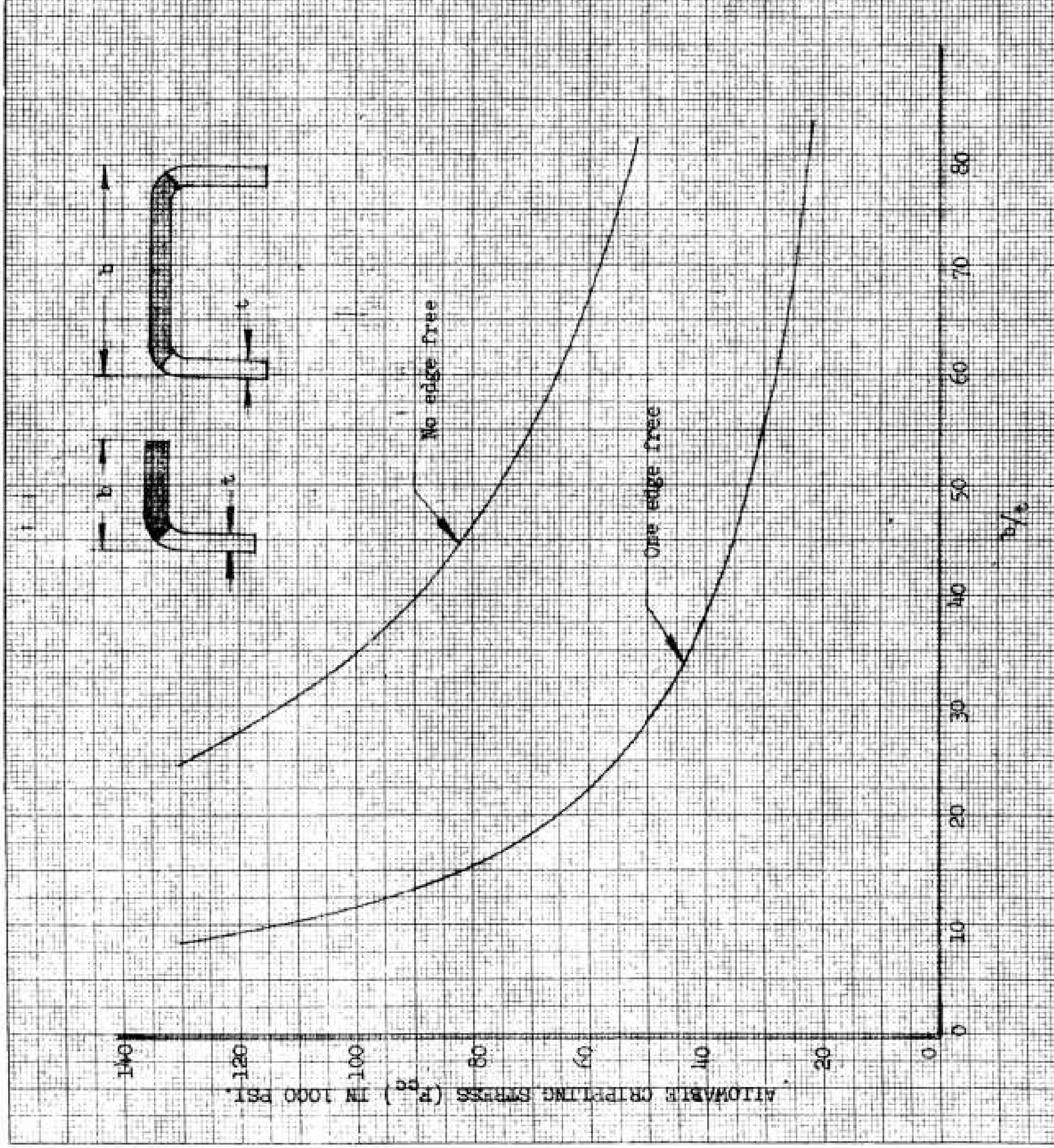
Figure 2.2-1
RENE' 41
(H.T. 1950°F, ½ hr +1400°F;16 hrs)
F_{bru}
F_{tu}
F_{cy}
F_{ty}
F_{su}
F_{bry}
TENSILE ULT. & YIELD; COMPR. YIELD, SHEAR ULTIMATE STR. (1000 psi)
BEARING ULT. & YIELD STR. (1000 psi)
TEMPERATURE °F
Diameter or thickness, inches | Percent of Values on curves
Under .015 | 85
.015 to 3.000 | 100
3.00 through 4.50 | 95
Over 4.50 | 90
DENSITY = .298 lbs. per cu. in.
Dashed lines show estimated values
K&E 10 X 10 TO THE CM. 359-14 KEUFFEL & ESSER CO.

Figure 2.2-2

RENE' 41

FORMED AND EXTRUDED
ALLOWABLE CRIPPLING STRESS

Heat treated to Mod. High Temperature
HT. 165000 psi



K+E 10 X 10 TO THE CM. 359-14
KEUFFEL & ESSER CO. MADE IN U.S.A.

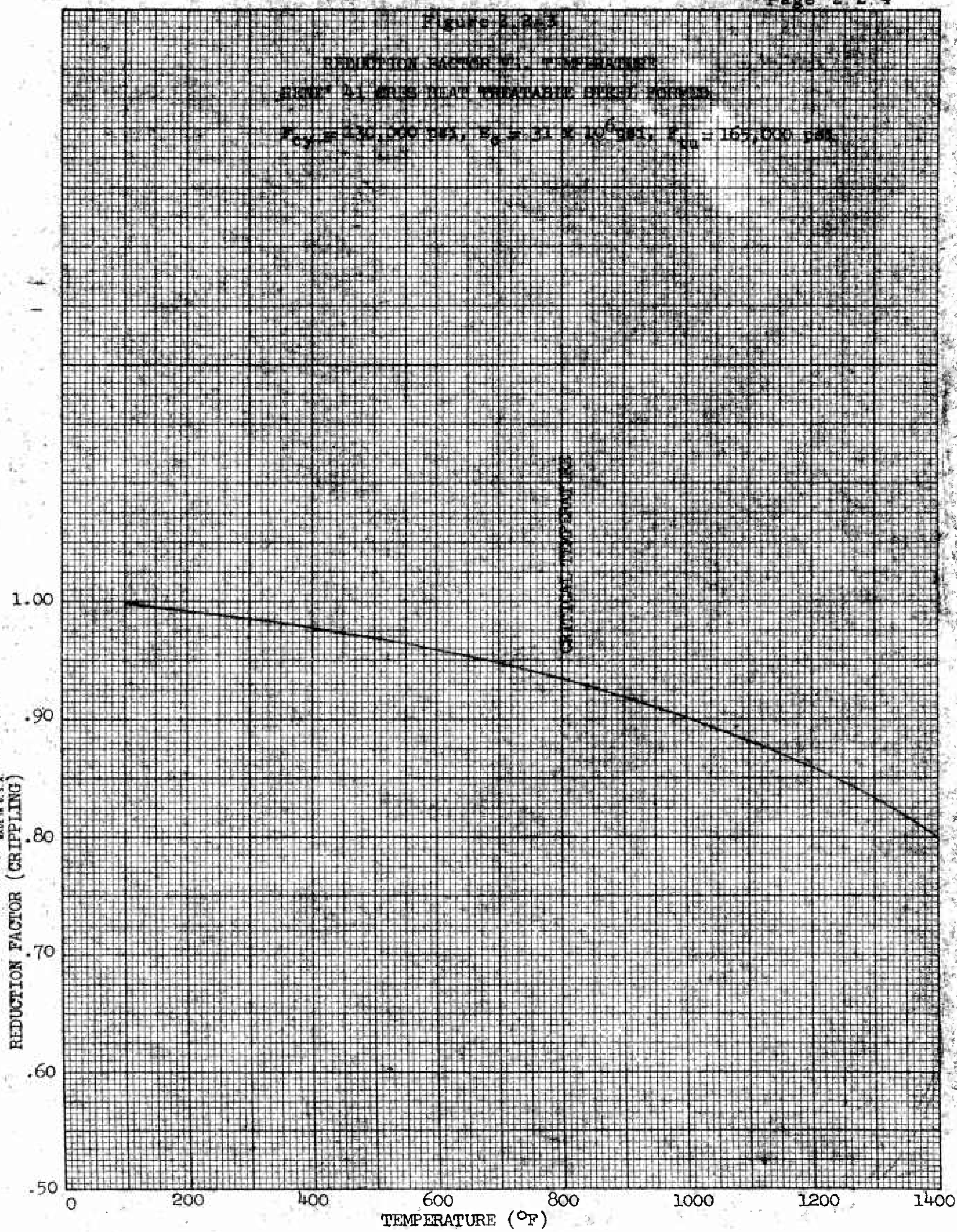


Figure 2.2.3
REDUCTION FACTOR VS. TEMPERATURE
HEAT TREATABLE STEEL FORMED
F_{cy} = 130,000 psi, E_c = 31 x 10^6 psi, F_{tu} = 165,000 psi
CRITICAL TEMPERATURE
REDUCTION FACTOR (CRIPPLING)
1.00
.90
.80
.70
.60
.50
0
200
400
600
800
1000
1200
1400
TEMPERATURE (°F)
359-11 KEUFFEL & ESSER CO.
10 X 10 to the 1/2 inch, 5th lines accented.
MADE IN U.S.A.

2.3 STAINLESS STEELS: (18 Cr - 8 Ni)

Type 301-1/2 hard corrosion resistant steel sheet was used for the skin over the Duct-Rib Subassemblies. This material provided stiffness, corrosion resistance and ease of fabrication by conventional joining methods. Operating temperatures of the skin areas were low enough to be out of the sensitizing range for the material and also low enough not to affect its work hardened properties materially. Design allowables were adequate for the applications.

Type 301 - full hard material was used for the Blade Retention Straps to provide high strength and corrosion resistance. Here again operating temperatures were low enough not to affect the work hardened properties beyond the point where design allowables were adequate.

Type 321 and 347 corrosion resistant steels were used for the Inboard Blade Ducts and the Hub Ducts. These assemblies required welding for their fabrication and since they were operated in the sensitizing temperature range, the stabilized grades of material were selected. The 347 grade only was specified in the area when the highest possible strength allowables were required.

Generally type 321 and 347 alloys were selected because of their good strength and elevated temperature corrosion and oxidation resistance and the fact that they have good weldability and formability.

t of steel · 18% Cr - 8% Ni, Ti - type 321 (U·S·S 18-8Ti)

Similar Specification Numbers	Heat Treatment	Chemical Composition	
A 269-47, TP 321	Cool Rapidly from 1750-1950F	Carbon	0.08 max.
A 271-47, TP 321	Stabilizing Treatment 1550-1650F	Manganese	2.00 max.
A 213-46, TP 321		Phosphorus	0.03 max.
A 158-47T, P8b		Sulphur	0.03 max.
A 182-46, F8t		Silicon	0.75 max.
A 193-47T, B8		Chromium	17.0-20.0
A 240-44, T		Nickel	9.0-13.0
A 167-44, 5		Titanium	
A 276-44T, 321		5 x C (min.)	0.60 max.
ANS 757			

TENSILE PROPERTIES (1)

Test Temperature F	0.2% Offset Yield Strength 1000 psi	Tensile Strength 1000 psi	Elongation % in 2 in.	Reduction of Area %
70	33.0	85.0	58	75
300	29.0	68.5	49	76
500	26.0	62.0	43	74
700	23.0	59.5	38	71
900	20.5	56.0	37	70
1100	19.0	49.0	43	73
1300	16.5	37.0	56	78
1500	13.0	22.0	73	85
1700		15.5		
1900				
2100				
2300				

CREEP AND RUPTURE PROPERTIES (1)

Test Temperature F	Stress (1000 psi) for a Creep Rate of		Stress (1000 psi) for Rupture in	
	0.0001% per hr. (1% in 10,000 hrs.)	0.00001% per hr. (1% in 100,000 hrs.)	1,000 hrs.	10,000 hrs.
800				
900	25.0			
1000	18.3			
1100	13.0	12.5	27.0	16.0
1200	8.0		17.5	9.8
1300	4.8		10.0	6.0
1400	2.4		5.6	3.6
1500	0.9		3.7	2.2
1600	.5			

EFFECT OF TIME AND TEMPERATURE ON NOTCH IMPACT STRENGTH AND HARDNESS (2)

	Unexposed	Exposed 1000 hrs. at			Exposed 10,000 hrs. at		
		900F	1050F	1200F	900F	1050F	1200F
Charpy Keyhole Notch Impact Values (Ft-Lbs)	107	101	90	69	88	72	62
Brinell Hardness	136	143	149	166	156	151	148

Notes: (1) These data represent not only tests conducted in various laboratories throughout the United States Steel Corporation, but also data reported in the literature.

(2) All testing done at room temperature.

Material exposed without stress.

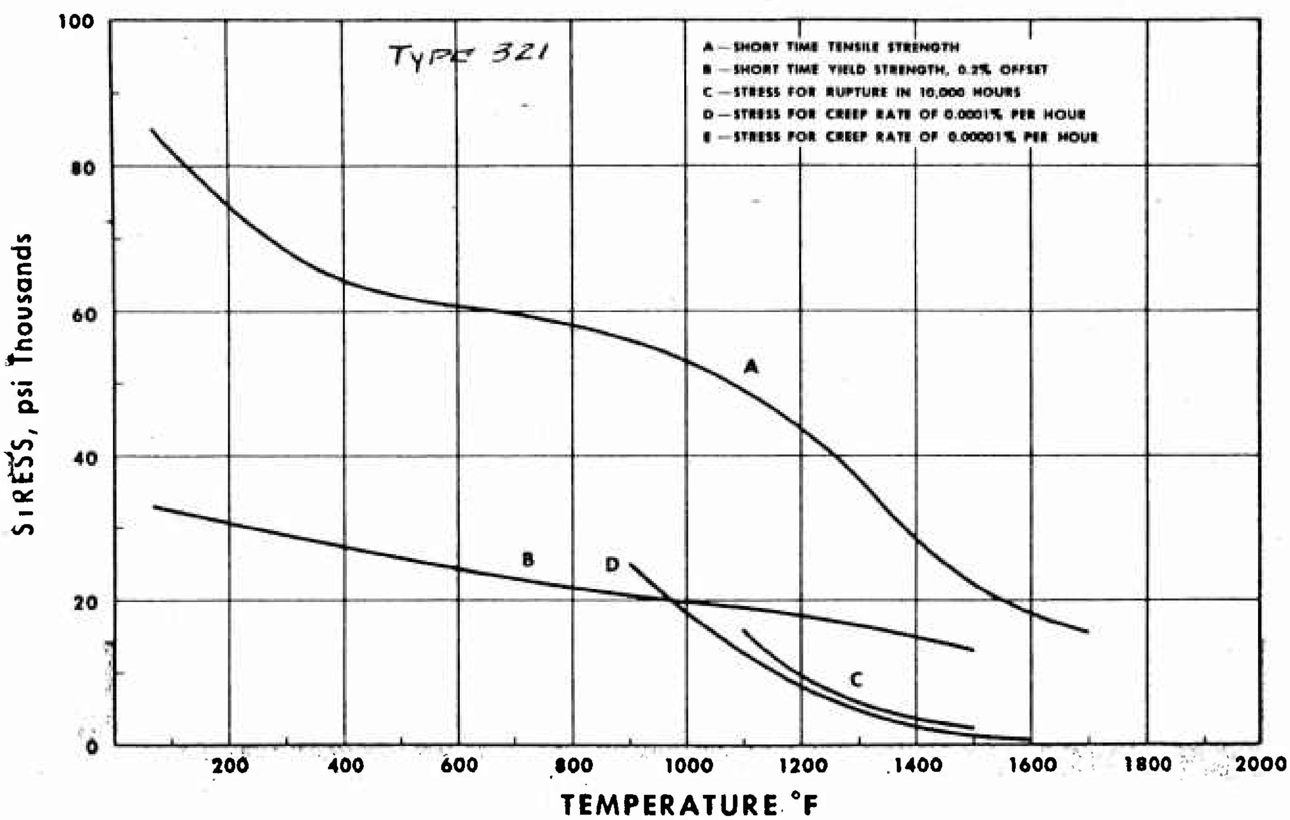


Figure 2.3-1

TYPE 321 Corrosion Resistant
Material Properties at Temperature

Type of steel: 18% Cr - 8% Ni - Cb - Type 347 (USS 18-8 Cb)

Similar Specification Numbers	Heat Treatment	Chemical Composition	
A 269-47, TP 347	Cool Rapidly from 1850-2050F	Carbon	0.10 max.
A 271-47, TP 347	Stabilizing Treatment 1550-1650F	Manganese	2.00 max.
A 213-46, TP 347		Phosphorus	0.03 max.
A 158-47T, P8d		Sulphur	0.03 max.
A 182-46, F8c		Silicon	0.75 max.
A 193-47T, B8		Chromium	17.0-20.0
A 240-44, C		Nickel	9.0-13.0
A 167-44, 6		Columbium	10 x C (min.), 1.00 max.
A 276-44T, 347			
ANS 757			

TENSILE PROPERTIES (1)

Test Temperature F	0.2% Offset Yield Strength 1000 psi	Tensile Strength 1000 psi	Elongation % in 2 in.	Reduction of Area %
70	39.5	91.0	50	71
300	34.0	74.5	47	75
500	32.0	69.0	41	74
700	32.0	67.0	35	72
900	31.5	64.0	35	69
1100	28.5	56.0	39	69
1300	24.0	40.0	51	74
1500	19.5	23.0	76	92
1700		14.0		
1900		9.5		
2100		5.5		
2300		4.0		

CREEP AND RUPTURE PROPERTIES (1)

Test Temperature F	Stress (1000 psi) for a Creep Rate of		Stress (1000 psi) for Rupture in	
	0.0001% per hr. (1% in 10,000 hrs.)	0.00001% per hr. (1% in 100,000 hrs.)	1,000 hrs.	10,000 hrs.
800				
900				
1000	19.6			
1100	13.5	11.2	30.4	22.0
1200	8.2	6.1	17.5	11.0
1300	4.6	2.4	11.0	4.6
1400	2.5		7.4	
1500	1.5		4.5	
1600	1.0			

EFFECT OF TIME AND TEMPERATURE ON NOTCH IMPACT STRENGTH AND HARDNESS (2)

	Unexposed	Exposed 1000 hrs. at			Exposed 10,000 hrs. at		
		900F	1050F	1200F	900F	1050F	1200F
Charpy Keyhole Notch Impact Values (Ft-Lbs)	56	60	55	49	63	51	32
Brinell Hardness	169	156	167	169	156	169	124

Notes: (1) These data represent not only tests conducted in various laboratories throughout the United States Steel Corporation, but also data reported in the literature.

(2) All testing done at room temperature.
Material exposed without stress.

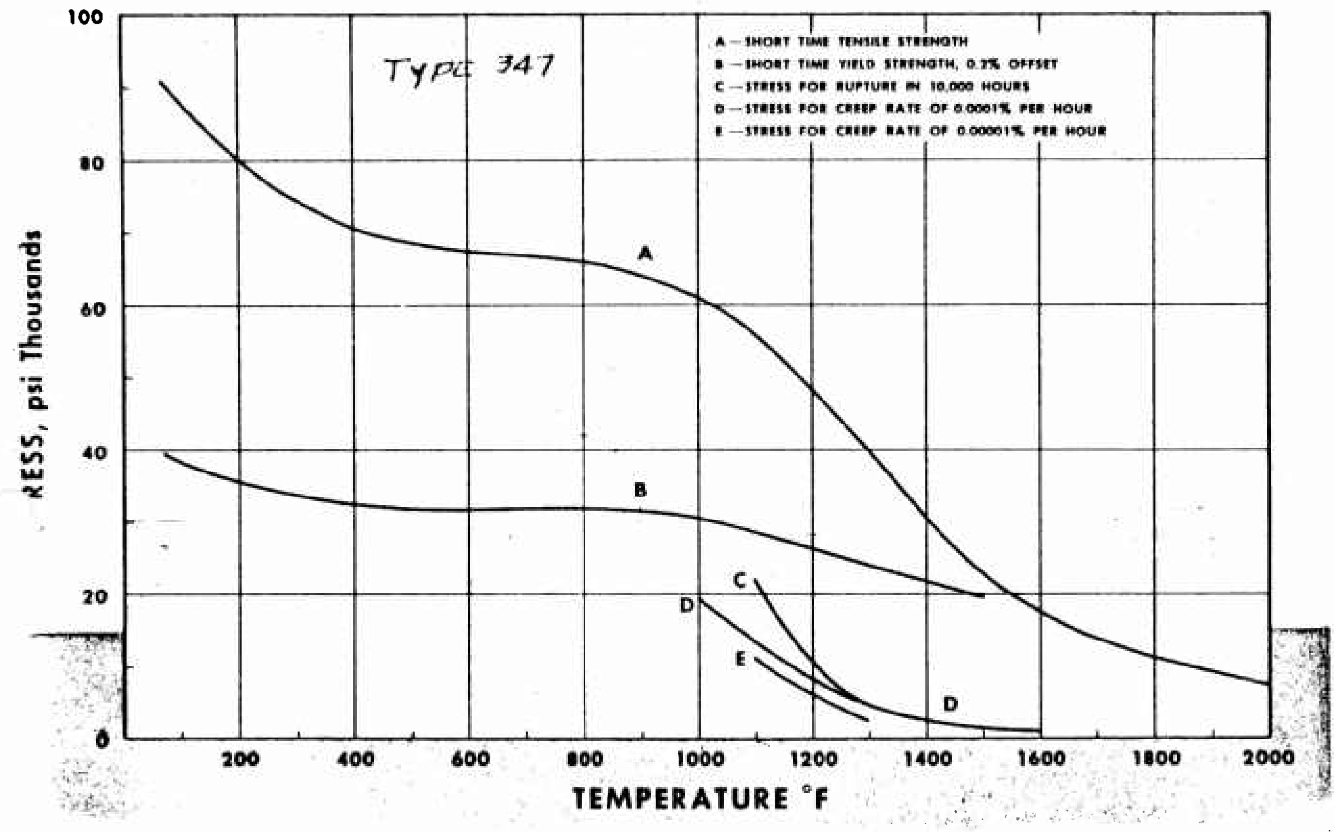


Figure 2.3-2

TYPE 347 Corrosion Resistant Steel
Material Properties at Temperature

2.4 INCONEL X: BASIC ANALYSIS

70%	Ni & Co
14 - 17%	Cr
5 - 9%	Iron
2.25 - 2.75%	Ti

This alloy was used for some of the Blade Flexures, the Duct Transition Section and the Inboard Duct Flexures. The selection of Inconel X for these assemblies was based on the need for a high temperature alloy which could be readily formed into complicated shapes and which was easily welded by both fusion and resistance processes and could be subsequently aged to obtain the higher strength required. Corrosion and oxidation resistance at elevated temperatures are excellent. In view of these qualities the alloy has been used extensively for gas turbine and jet engine high temperature applications.

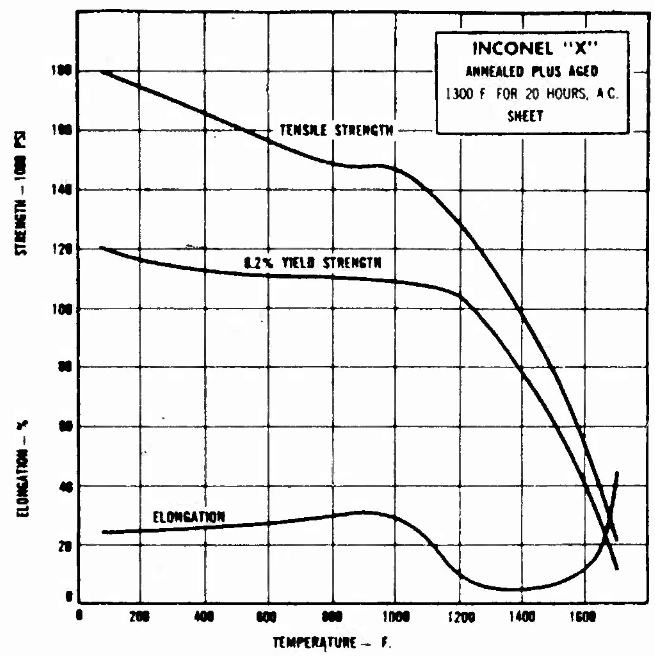


Fig. 2.4-1 Tensile Properties of Cold Rolled, Annealed, and Aged Sheet

2.5 HAYNES #25: BASIC ANALYSIS

1 - 2%	Mn
9 - 11%	Ho
19 - 21%	Cr
14 - 16%	W
3% Max.	Iron
Balance	Co

Haynes #25 alloy was selected for use on the Tip Cascade Assemblies because of its resistance to oxidation and carburization at temperatures up to 1900°F. Formability was recommended as being good and fabrication by resistance and fusion welding presented no particular problem. The material was known to have performed well in high temperature turbine blade and afterburner applications. Performance of the material at the operating temperatures (1050 - 1200°F) in this application was anticipated to be good.

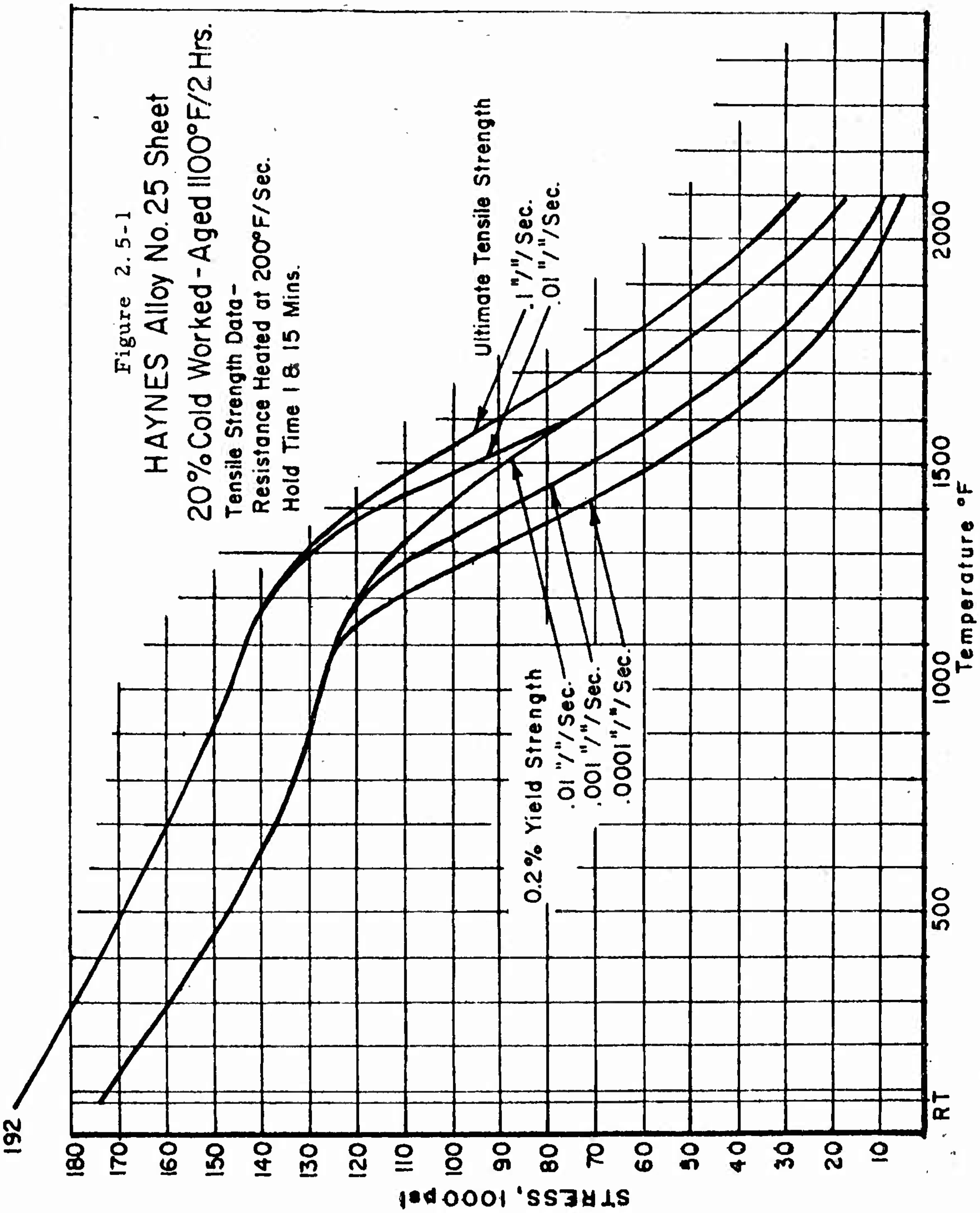


Figure 2.5-1
HAYNES Alloy No. 25 Sheet
20% Cold Worked - Aged 1100°F/2 Hrs.
Tensile Strength Data-
Resistance Heated at 200°F/Sec.
Hold Time 1 & 15 Mins.

2.6 ELECTROFORMED NICKEL

This method of forming was used to produce some of the commercially pure nickel flexures between the blade sections. It seemed on the basis of preliminary investigations to be the most desirable way of producing the complicated bellows shapes which were to provide flexibility and resist moderately high temperatures. There was, however, considerable trouble in getting the flexures delivered from the vendors on schedule so an alternate method of fabricating these parts from stampings of Inconel "X" alloy was used.

2.7 TITANIUM

6 Al-4 V titanium alloy was selected for use in the Blade Spars and for the Skins on the inboard transition area and the tip aft fairing.

Selection of this alloy for the spars was based on its high strength-weight ratio in the operating temperature range encountered. The sheet form of this alloy was used in areas where there was a minimum of forming since forming is more difficult with this allow.

Commercially Pure Titanium:

This alloy was selected for use on the Tip Aft Segment ribs and fairing because somewhat severe forming was required and because the fairing was to be joined by fusion welding. Strength-weight advantage was acceptable at the expected operating temperatures.

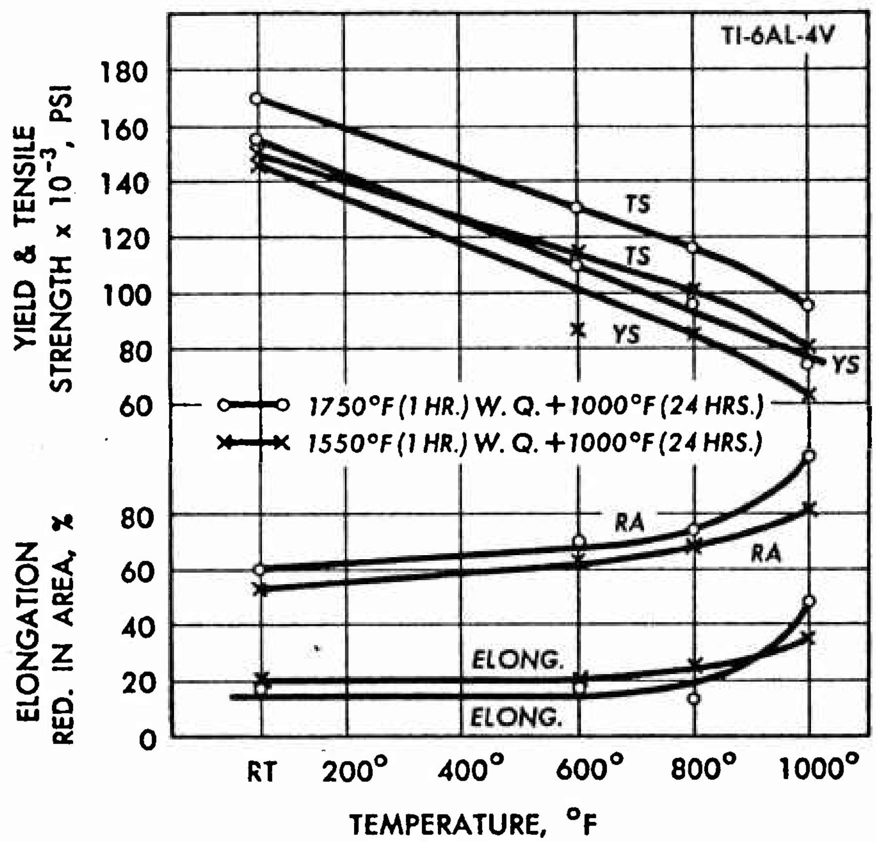


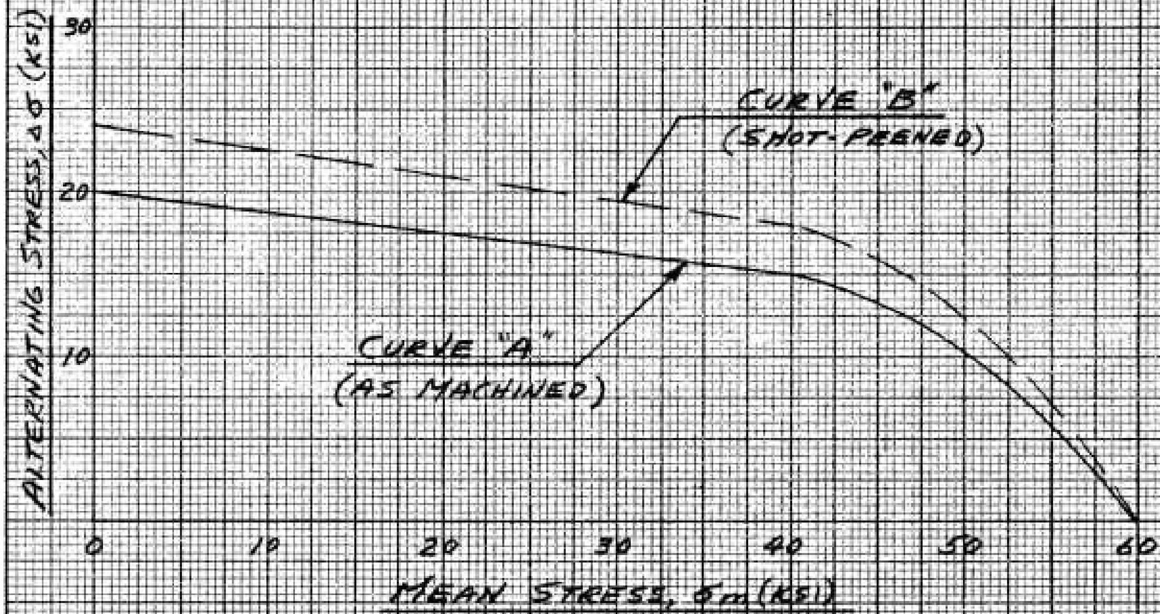
Figure 2.7-1

Elevated temperature tensile properties.

FIGURE 2.7-2

DESIGN FATIGUE ALLOWABLE CURVES

6AL-4V TITANIUM SPARS



REFERENCE TABLE

DATA REFERENCE		MAT'L	K_t	σ_{MAX}	R	σ_m	$\Delta\sigma$
TMCA REPORT (FIG. 7)		6AL-4V SHEET	3.5	59,500	.26	37,500	±22,000
		6AL-4V SHEET	0	124,000	.26	99,000	±24,800
BATTELLE MEMO REPORT DATED 2-28-58	(FIG. 51)	6AL-4V EXTR.	2.0	40,000	.02	20,000	±20,000
	(FIG. 54)	6AL-4V (400°F)	4.6	45,000	-1.0	0	±45,000
	(FIG. 54)	6AL-4V (600°F)	4.6	38,000	-1.0	0	±38,000
TML REPORT 77 DATED 7-17-57	(FIG. A-21)	6AL-4V BAR	3.75	56,000	.02	28,000	±28,000
	(FIG. A-22)	6AL-4V ROD	2.02	47,000	-1.0	0	±47,000
	(FIG. A-23	6AL-4V ANNEALED BAR	3.0	30,000	-1.0	0	±30,000

2.8 ALLOY STEELS

4130 and 4340 steels were used in the Gimbals, Mast Assemblies, and control assemblies.

Since these were not subject to higher operating temperatures, they only involved conventional heat treatment and finishing procedures in their construction. The choice between these two alloys was dependent on the section thickness and ultimate tensile strength required.

HUGHES TOOL COMPANY — AIRCRAFT DIVISION

ANALYSIS Hot Cycle Rotor MODEL 285 REPORT NO. 285-13 PAGE 2.8.2

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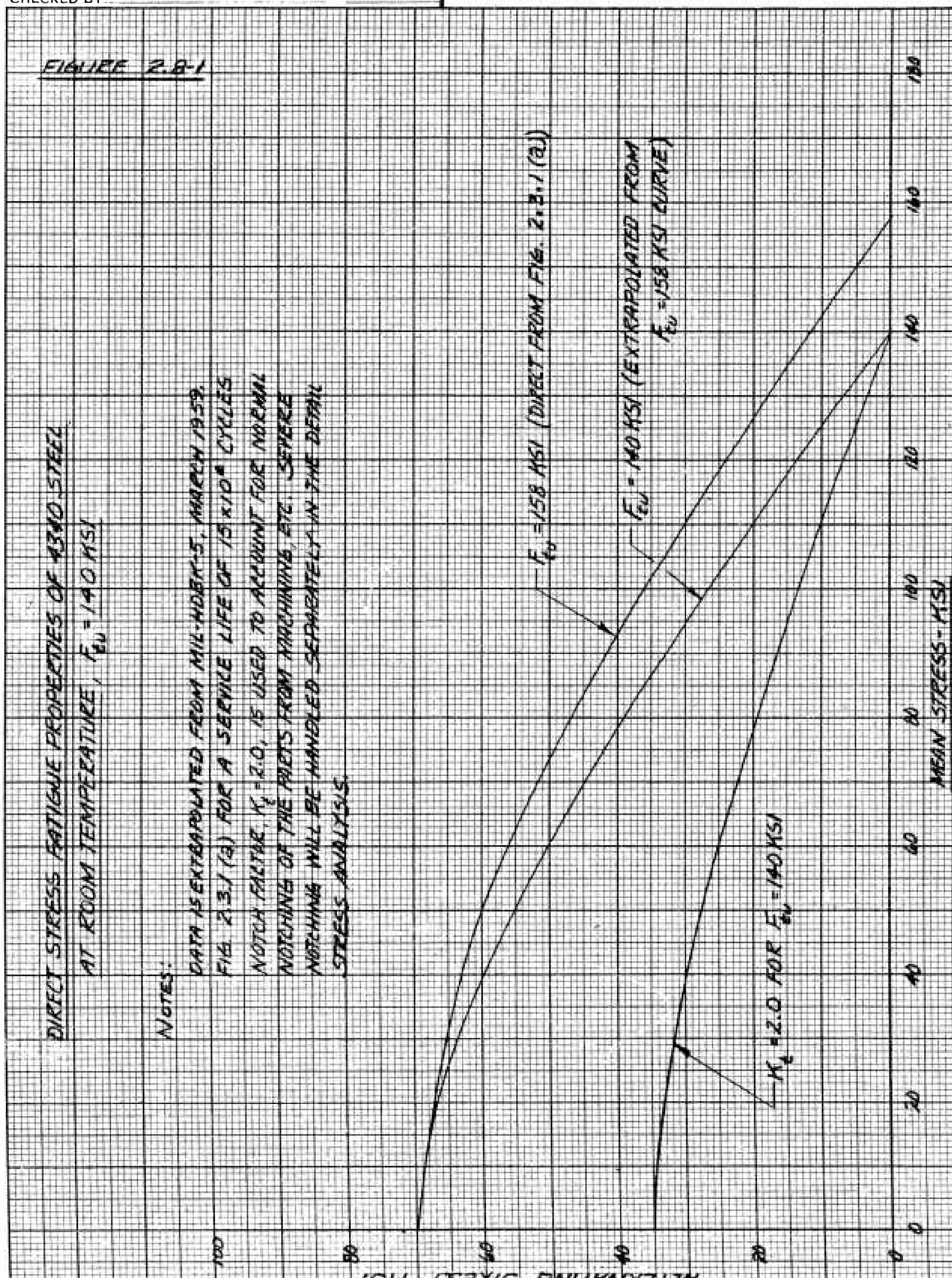
ALLOY STEELS



"ALBANENE" NO. 195T

FORM NO. 9726

2.9 ALUMINUM ALLOY

2024 T 3 alclad sheet was used for the Blade Trailing Edge sections and for the skin near the inboard ends of the blades. High operating temperatures were not involved so this selection provided a light weight material with good corrosion resistance, and one which could be fabricated by conventional methods. Operating temperatures did not exceed approximately 200°F.

356 - T6 casting alloy was used for the Feathering Ball, heat treated to obtain greater strength and hardness. It lends itself readily to producing high quality castings of complicated shapes. Operating temperature of this assembly did not exceed 290°F.

SECTION 3

WEIGHT ANALYSIS

CONTENTS

3. 1 INTRODUCTION

In the design of the Hot Cycle Rotor System the major emphasis was placed on designing and producing a rotor system to prove the feasibility of the concept on a fixed test stand. Inasmuch as the blade structure presented the greatest challenge, considerable effort was placed on developing blades that would be effective on both the test stand and on a subsequent flight vehicle. The usual weight considerations were therefore incorporated into the blade design and the blade weights noted herein can be considered representative for hot cycle rotors in this size and configuration. It is estimated that weight reductions in the order of 5 to 10% can be effected on a subsequent redesign of these blades. The hub, ducts inboard of the blade root, rotor control system, and the rotor mount were purposely designed and built conservatively in order to reduce the cost. As a result, these components are considerable overweight for a flying helicopter and are subject to redesign for an optimum weight configuration. The actual weight summation for the various functional groups of the rotor system are presented in the following paragraphs.

3.2 SUMMARY: HOT CYCLE ROTOR WEIGHTS

ITEM	WEIGHT - POUNDS		
	Present Test Stand Components	Possible Weight Reduction	Redesigned Flying Components
Blades (3)	1642	-82	1560
Hub and Gimbal	850	-160	690
Total - Rotor Group	2492	-242	2250
Pylon	99		99
Ducts and Seals	284	-84	200
Control System - Rotor	556	-206	350

3.3 BLADE ASSEMBLY

The completed assemblies of the blade were weighed on a 4 point platform in order to check the position of the center of gravity and the total weight. The total blade weight includes all components outboard of the ball and socket joint at the inboard end of the shank including the ducts and the retention straps. For dynamic balance, two blades were balanced to the third blade by adding or subtracting balance weights to equalize the span-wise weight moment. The blades are color coded to differentiate among them. The results of actual weighing, adjusted to the standard configuration and dynamic balance, are as follows:

	W Lb.	X In.	WX In. Lb.	r In.	Wr In. Lbs.
Yellow Blade	545	8.2	4480	129.9	70.884
Red Blade	547	7.9	4326	129.6	70.884
Blue Blade (Instrumented)	550	8.0	4412	128.8	70.885
Total - 3 Blades	1642				

1. X is measured from the leading edge
2. r is measured from the ℄ rotation.

These blade weights were approximately 10% higher than the calculated blade weights. The additional weight can be attributed to sealant at duct joints and to some increases in duct installed weight.

A radial distribution of blade weight is presented in Figure 3.1.

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ANALYSIS

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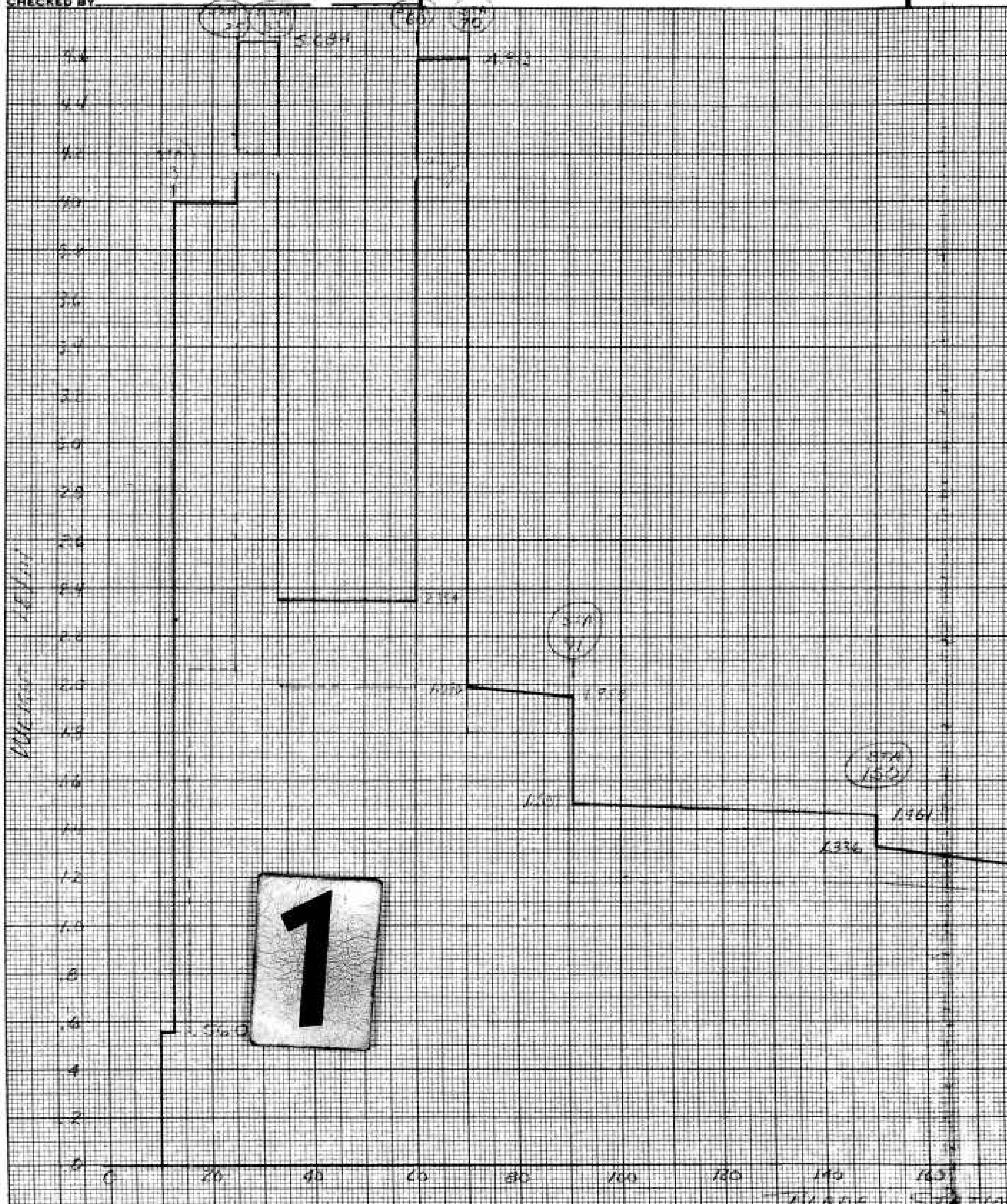


"ALBANY" NO. 195T

FORM NO. 725

PAGE

FIGURE 3.1

HOT CYCLE ROTOR BLADE
SPANWISE WEIGHT DISTRIBUTION
REVISED TO REFLECT ACTUAL WT. DATA

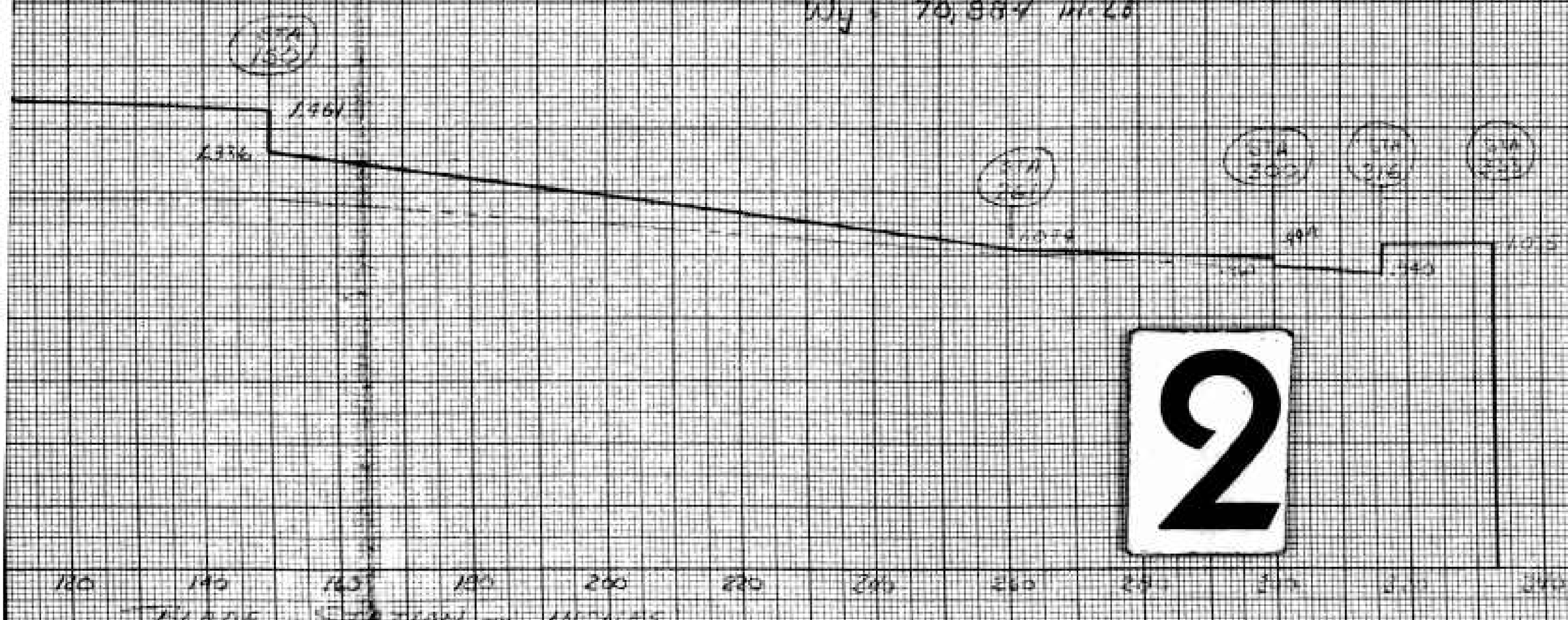
J.A.C.
4-28-61

	W LB	y IN	Wy IN-LB
COMPLETE BLADE	541.5	130.4	70,604 *
LESS: INBD DUCT	− 27.3	21.2	− 579
TOTAL BLADE LESS INBD DUCT	514.2	(136.2)	70,025
LESS: STRAPS	− 35.4	41.0	− 1451
TOTAL BLADES LESS STRAPS AND INB'D DUCT	478.8	(143.2)	68,574

——— CALC WT. DIST. CURVE OF 7-15-60

* NOTE: THIS COMPARES REASONABLY WELL WITH ACT WT. OF 2-1-62

WT = 547 LB
y = 129.6 IN.
Wy = 70,884 IN-LB



3.4 HUB ASSEMBLY

The hub assembly for this Hot Cycle Rotor includes the upper gimbal, the bearings and races, the brg. housing structures, and the rotor shaft. The total weight of these components as installed in the test stand is 850 pounds. It is estimated that a redesign of these components for a flight artical could effect a weight reduction of 160 pounds, thus lowering the weight to 690 pounds. The present components were designed without weight control and built for function only, in order to reduce cost and construction time.

3.5 DUCT ASSEMBLY

The duct assembly for the Hot Cycle Rotor includes the non-rotating elbow, the upper rotating elbow, the seal installation between the two ducts and the clamps and gaskets required. This portion of the test stand simulates the duct system (for a flight article) between the diverter valve and the blades. The total weight of the test stand components is 224 pounds. It is estimated that this weight could be reduced to 200 pounds by utilizing Inconel X instead of corrosion resistant steel.

3.6 PYLON

The pylon or rotor mount consists of the welded steel tube structure supporting the upper and lower bearing housings of the hub. The actual weight of this unit including attaching bolts is 99 pounds.

3.7 CONTROLS - ROTOR

The weight for Rotor Controls includes the upper and lower swashplates and all of the linkages and supports for the system up to the blade incidence arms. The summation of weights for these component is 556 pounds. The rotor control system components have been designed and built to perform the control function. No effort was made to remove excess material or to optimize the structure. It is estimated that the weight of these components could be reduced to 350 pounds for a well designed flight article.

3.8 DETAIL WEIGHT STATEMENT

A weight statement of the rotor components is presented in detail on pages 3.4.1 through 3.4.8. This statement is of sufficient detail to permit a detailed weight analysis.

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ANALYSIS Detail Weight Statement
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285-0100 Hot Cycle Rotor Blade Assembly

		No. Req.	Weight - lbs. One Blade	
285-0188	Tip Installation	(1)		14.22
-0171	Tip Assem-Fwd.	(1)	5.92	
-0172	Cascade Assembly	1	5.45	
-0173	Tip Assem-Aft.	1	1.10	
-0187	Fairing-Aft Tip	1	.45	
-0123	Fairing-Nose	1	.65	
-0167	Coupling	1	Incl. in 0167	
	Nuts, Bolts, etc.		.65	
285-0170-5	Spar-Aft (incl. 285-0223 Doubler)			41.50
285-0170-3	Spar-Fwd.			74.30
285-0167	Segment Installation-Fwd.			126.40
-0113	Segment	(18)	106.56	
-0165	Coupling	(3)	2.82	
-0167-3	Heat Shield	(38)	1.52	
-0203	Coupling	(16)	13.76	
	Nuts, Bolts, etc.		1.74	
285-0166	Structure Install. Sta. 33-63	1		25.89
285-0159	Duct Install. Sta. 15.50 to 92.00	1		59.60
-0162	Housing Assembly		11.50	
-0160	Duct Assembly		23.93	
-0137	Valve Assembly		4.75	
-0132	Duct Assembly		16.45	
-0194	Turn Buckle Assembly	(2)	.42	
-0195	Duct Assembly	1	.50	
-0507-7	Gasket	(2)	.02	
-9	Gasket	(2)	.04	
-11	Gasket	(1)	.02	
-0141-5	Clamp	(2)	.40	
-0141-3	Clamp	(2)	.84	
-9	Clamp	1	.45	
-0196	Clevis	(2)	.16	
	Nuts, Bolts, etc.		.12	
285-0155	Bearing Assembly - Feathering	(1)		7.00
285-0139	Struct. Install. - Sta. 63 - Sta. 73	(1)		31.17
285-0138	Struct. Install. - Sta. 74 - Sta. 91	(1)		10.50
285-0127	Struct. Install. - Sta. 24.25 - 33.25	(1)		47.34
285-0125	Fairing Install. - Rear - Sta. 24.25 - 91	(1)		1.40
285-0124	Fairing Install. - Fwd. - Sta. 24.25 - 91	1		1.46
285-0123	Fairing Install. Nose (incl. Bal. Wts.)	(1)		28.77
	C Sta. 96.50		1.71	
	109.5		1.71	
	121.5		1.71	
	134.0		1.87	
	146.0		1.87	
	159.0		1.87	
	171.5		1.81	
	184.5		1.81	

(Continued)

		No. Req.	Weight - lbs. One Blade	
	C Sta. 196.5		1.81	
	209.0		1.65	
	221.0		1.65	
	234.0		1.65	
	246.5		1.38	
	259.0		1.38	
	271.5		1.38	
	284.0		1.17	
	296.0		1.17	
	209.0		1.17	
285-0121-5	Strap Assembly - Front	(1)		19.08
-3	Strap Assembly - Rear	(1)		19.16
	Bolts, Nuts, etc.			2.90
285-0117	Segment Assembly - Aft.	(18)		16.56
	Bolts, Nuts, etc.			.90
285-0133	Droop Stop Installation	(1)		1.61
-0198	Shim	1		1.00
	Bolts, Nuts, etc.			3.25
	RTV Sealants (dry)*			14.00
TOTAL				548.01

*NOTE: Because of a sealing problem that arose during fabrication of the whirl test rotor a large quantity of sealant was used. This problem has been solved and subsequent blades will require only a fraction of the 14 pounds.

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ANALYSIS Detail Weight Statement | MODEL | REPORT NO | PAGE 3.4.3

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285-0514 Gimbal Assembly, Hot Cycle Hub

		No. Req.	Weight - Lbs. One Blade
285-0527	Trunnion Assembly	(1)	18.23
-0528	Ring Assembly	(1)	37.00
-0529	Fitting	(1)	50.35
-0530-3	Retainer Assem. Incl -5, & -7	(2)	2.20
-9	Insert	(2)	.50
-11	Spacer	(2)	.10
-13	Retainer	(2)	1.10
-15	Shield	(4)	.10
-17	Shield	(2)	.08
-19	Spacer	(2)	.06
-21	Lock	(2)	.02
-23	Plate	(2)	.26
-25	Shim	1	-
21309	Bearing	4	8.40
	Hardware		1.61
TOTAL - Gimbal Assembly			120.01

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ANALYSIS Detail Weight Statement | MODEL | REPORT NO |

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285-0500 Hub Installation Hot Cycle Rotor

		No. Req.	Weight - Lbs. One Blade
285-0533	Spacer	(1)	2.04
-0584	Spacer	(1)	10.50
-0310-17	Conduit	(4)	.08
-0543	Sleeve	(1)	1.50
-0524	Housing Assem.	(1)	29.00
-0546	Bearing - Shaft Upper	(1)	13.00
-0552	Inner Race - Hub Upper	(1)	39.50
-0553	Outer Race - Hub Upper	(1)	52.81
-0516-3	Retainer - Hub Upper Brg.	(1)	2.50
-5	Retainer	(1)	3.13
-7	Retainer	(1)	2.38
-9	Retainer	(1)	1.63
-0518	Spacer - Shaft	(1)	5.65
-0585	Seal Install.	(1)	.06
-0516-13	Shim	(1)	.05
-15	Shim	(1)	.08
-0310-3	Nut	(1)	3.98
-0310-5	Washer	(1)	.10
-0556-3	Seal - Upper Brg.	(1)	.40
-5	Seal - Upper Brg.	(1)	.40
-0511	Hub Assembly		445.72
	Misc. Hardware, etc.		19.29
TOTAL - Hub Installation			633.80

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ANALYSIS Detail Weight Statement MODEL REPORT NO

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285-0534 Shaft Assembly Hot Cycle Hub

		No. Req.	Weight - Lbs. One Blade
285-0517	Shaft		
-0515	Spoke	(1)	69.10
-0554	Washer	(1)	26.40
		(3)	.03
	Hardware		
			.17
TOTAL - Shaft Assembly			
			95.70

285-0523 Mount Assembly Hot Cycle Hub Truss

		No. Req.	Weight - Lbs. One Blade
285-0523	Assembly	(1)	95.0
	Hardware		4.0
TOTAL WEIGHT - Pylon			99.0

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ANALYSIS Detail Weight Statement MODEL REPORT NO PAGE 3.4.7
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Hub Duct Installation

		No. Req.	Weight - Lbs. One Blade
285-0522	Duct Installation - Lower	1	122.10
-0141-11	Clamp	2	.92
-0507-15	Gasket	2	.14
-0590	Duct Insulation	1	- *
-0509	Seal Installation	1	20.19
-0541	Duct Installation - Upper	1	80.50
TOTAL - Duct Installation - Hub			223.85

*Incl. in actual weights of duct.

285-0300 Rotor Upper Flight Controls

		No. Req.	Weight - lbs. One Blade
285-0326-3	Rod End - Act. Cylinder	(3)	9.83
	Nut - AN 315-14	(3)	.74
-0313-5	Swash Plate Asst. - Fixed	(1)	73.94
	Includes:		
-0313-3	Spacer	(1)	
	Bearing - Fafnir Y176PWI	(2)	
-0316	Bearing Assy - Swash Plate Supt.	(1)	
-0312-3	Swashplate - Rotating Assy.	(1)	69.07
	Includes:		
-0312-5	Retainer - Swash Plate Brng.	(1)	
	Hardware		
-0327	Spinder and Supt. Assy - Swasp. So.	(1)	35.49
	Includes:		
-0335	Link Assy - Swasp. Drive	(1)	
	Hardware		
-0336	Link Assy - Awasp. to Lwr. Beam	(2)	9.83
-0332	Drag Link Assy - Fixed Swash Plate	(1)	7.99
-0337-5	Beam - Lwr.	(1)	11.16
-0337-3	Beam Assy - Lwr.	(2)	15.32
285-0318	Collar (Incl. Hardware)	(1)	7.48
-0310-11	Seal Ring	(4)	.12
	Cone - Bearing - Timken 1380	(4)	1.14
	Cup - Bearing - Timken 1328	(4)	.58
	Garlock Klosure 76x7530	(8)	.16
-0310-13	Spacer	(4)	.12
-0307	Control Rod Assy (thru Mast)	(3)	38.19
-0337-7	Beam Assy - Top (Incl. Hardware)	(3)	69.51
285-0305-3	Control Rod Assy (Top Beam to Torque Tube)	(3)	10.94
-0303	Torque Tube Assy.	(3)	106.50
-0305-5	Control Rod Assy. (To Blade)	(3)	14.46
-0306	Suppt. Assy.		15.86
	Hardware, Total		13.07
TOTAL - 285-0300 Rotor Upper Flight Controls Installation			511.50
285-0330	Support Assem. - Torque Tube (From Dwg.	(3)	21.63
-0331	Support Assem. - Torque Tube 285-0511)	(3)	22.65
TOTAL - Rotor Head Flight Controls			555.78

SECTION 4

DESIGN LOADS

CONTENTS

4. 1 INTRODUCTION

This section presents the design loads used for design and structural analysis of the Hot Cycle Rotor. Included in this section are Blade Loads and Hub and Shaft Loads. Control System Loads, for convenience are presented at the beginning of Section 5. 4 (Controls Analysis). Loads as presented are limit unless specified otherwise and are based on the structural criteria of Section 1.

Conditions considered are as follows:

(1) Weighted Fatigue (or Modified Approach-To-Land)

(2) 2-1/2 G Maneuver

(3) Flat Pitch Over-Speed

(4) Ground Flapping

There is a minor discrepancy in the analysis, mainly in centrifugal loads, due to increase in the blade final weight. Some allowance has been made in the structural analysis (Section 5) which partially takes this into account.

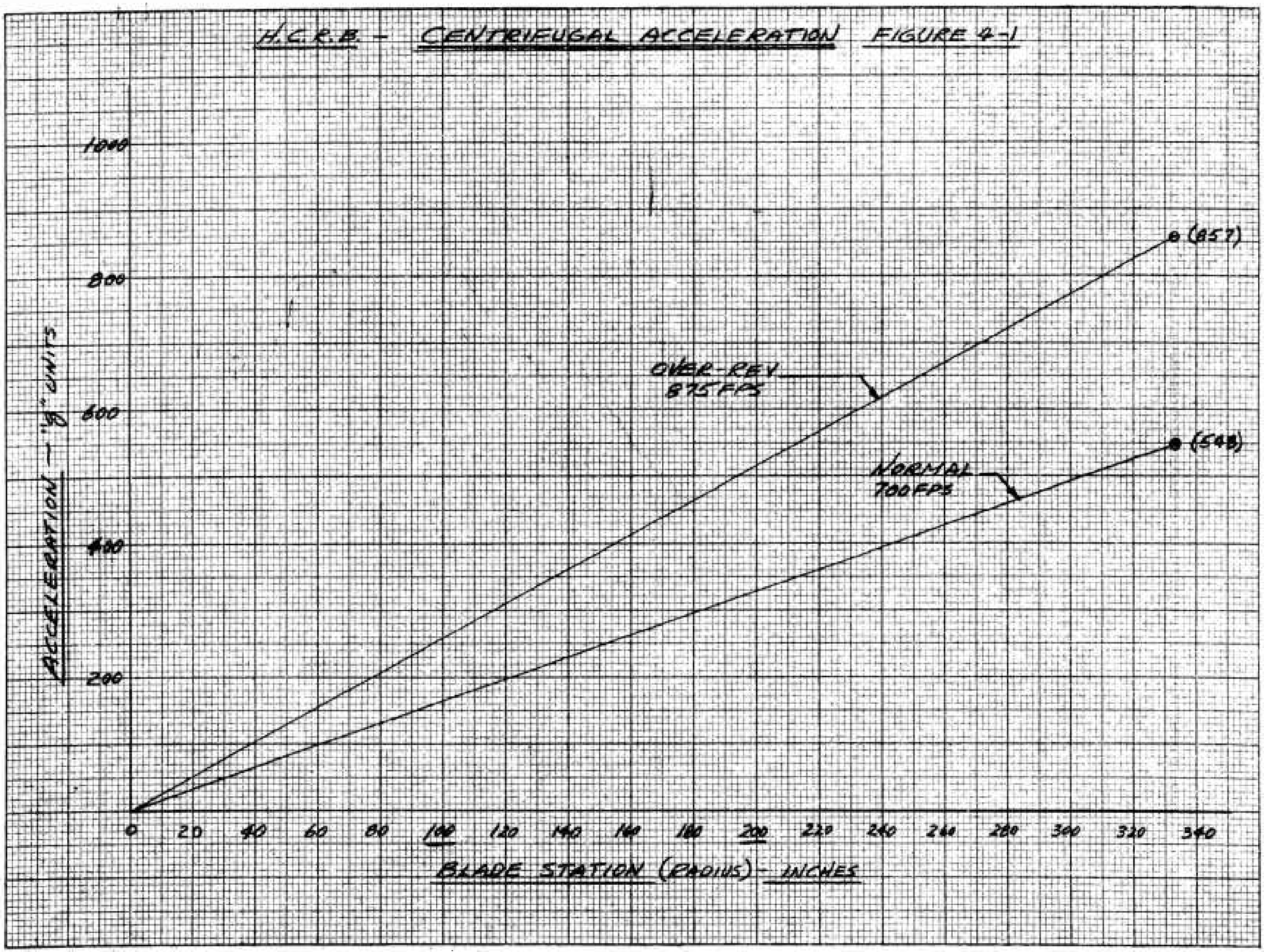
4.2 BLADE LOADS

Blade loads are presented on the following pages for the Design Conditions Listed on page 4.1. In addition loads are shown for the rotor starting condition. Wind loads specified in Section 2 were checked and found non-critical.

TABLE 4.2-1 BASIC DATA

Parameter \ Condition	Weighted Fatigue	2-1/2G Maneuver	Flat Pitch Over-Rev	Ground Flapping
Design Gross Weight	15,300 lbs.	15,300 lbs.	15,300 lbs.	15,300 lbs.
Blade Tip Speed	700 fps	700 fps	875 fps	0
Load Factor (Limit)	1.5	2.5	0	2.5
Coning Angle	$4.0 \pm 0.5^{\circ}$	$10 \pm 0.6^{\circ}$	0	—
Blade Feathering	$0 \pm 8.35^{\circ}$	$4.4 \pm 13.2^{\circ}$	0	—

Note: Blade centrifugal force loads are in error because of increase in final blade weight. A comparison between design and final values is shown in the curves of Figure 4-2.



K+E 10 X 10 TO THE 1/2 INCH KEUFFEL & ESSER CO. 359-11 MADE IN U.S.A.

ANALYSIS
PREPARED BY J. NEEDHAM 5/3/61
CHECKED BY

TABLE 4.2-2 CENTRIFUGAL FORCE

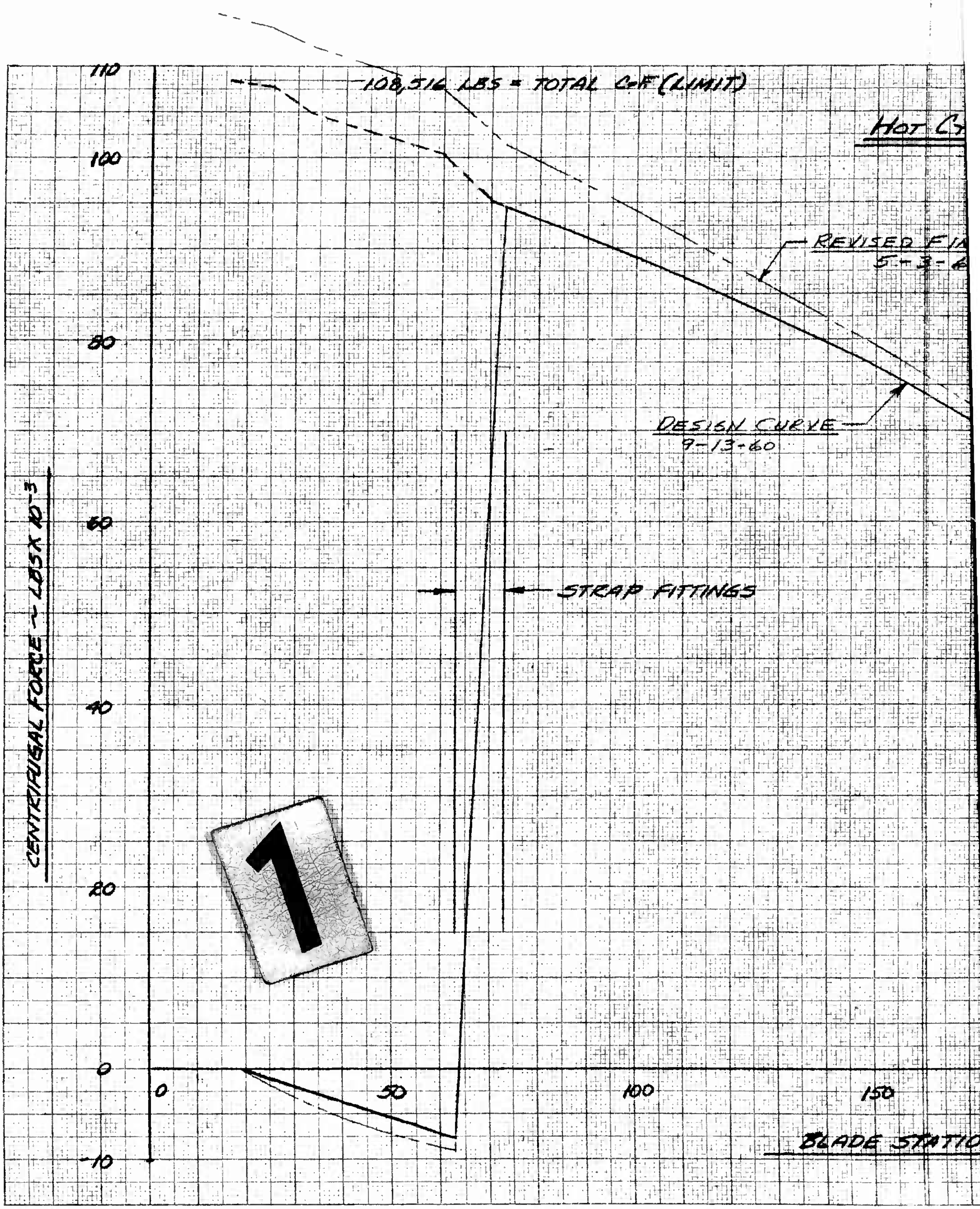
THE BLADE CENTRIFUGAL FORCE IS COMPUTED FOR THE NORMAL ROTOR TIP SPEED OF 700 FPS

$C.F. = \frac{W}{g} R \omega^2$, $\omega = \frac{V}{R} = \frac{700(12)}{333} = 25.2$ RAD./SEC., FOR R IN INCHES, W IN LBS. $C.F. = \frac{(25.2)^2}{386} WR = 1.645\, WR$

STATION	ΔL (IN.)	W_{AVG} (LB/IN)	W (LBS.)	y (IN.)	W·y (IN-LBS)	ΔC.F. (LBS)	ΣC.F. (LBS)		
							0		
333-316	17	1.035	17.6	324.5	5710	9390			
							9390		
316-300	16	.950	15.2	308.0	4680	7700			
							17090		
300-261	39	1.019	39.7	280.5	11140	18330			
							35420		
261-210	51	1.102	56.3	235.5	13260	21810			
							57230		
210-150	60	1.248	74.8	180.0	13460	22140			
							79370		
150-91	59	1.485	87.6	120.5	10560	17370			
							96740		
91-70	21	1.974	41.5	80.5	3340	5490			
							102230		
70-60	10	4.930	49.3	65.0	3200	5260			
							107490	(8520)	
60-33	27	2.354	63.5	46.5	2950	4850			
							112340	(3670)	
33-25	8	5.684	45.5	29.0	1320	2170			
							114510	(1500)	
25-13	12	4.00	48.0	19.0	910	1500			
			(539.0)				116010		

FOR OVER-REV. CONDITION INCREASE BY $\left(\frac{875}{700}\right)^2 = 1.56$

FORM 9707



10 X 10 TO THE CM 359-14L
KEUFFEL & ESSER CO.

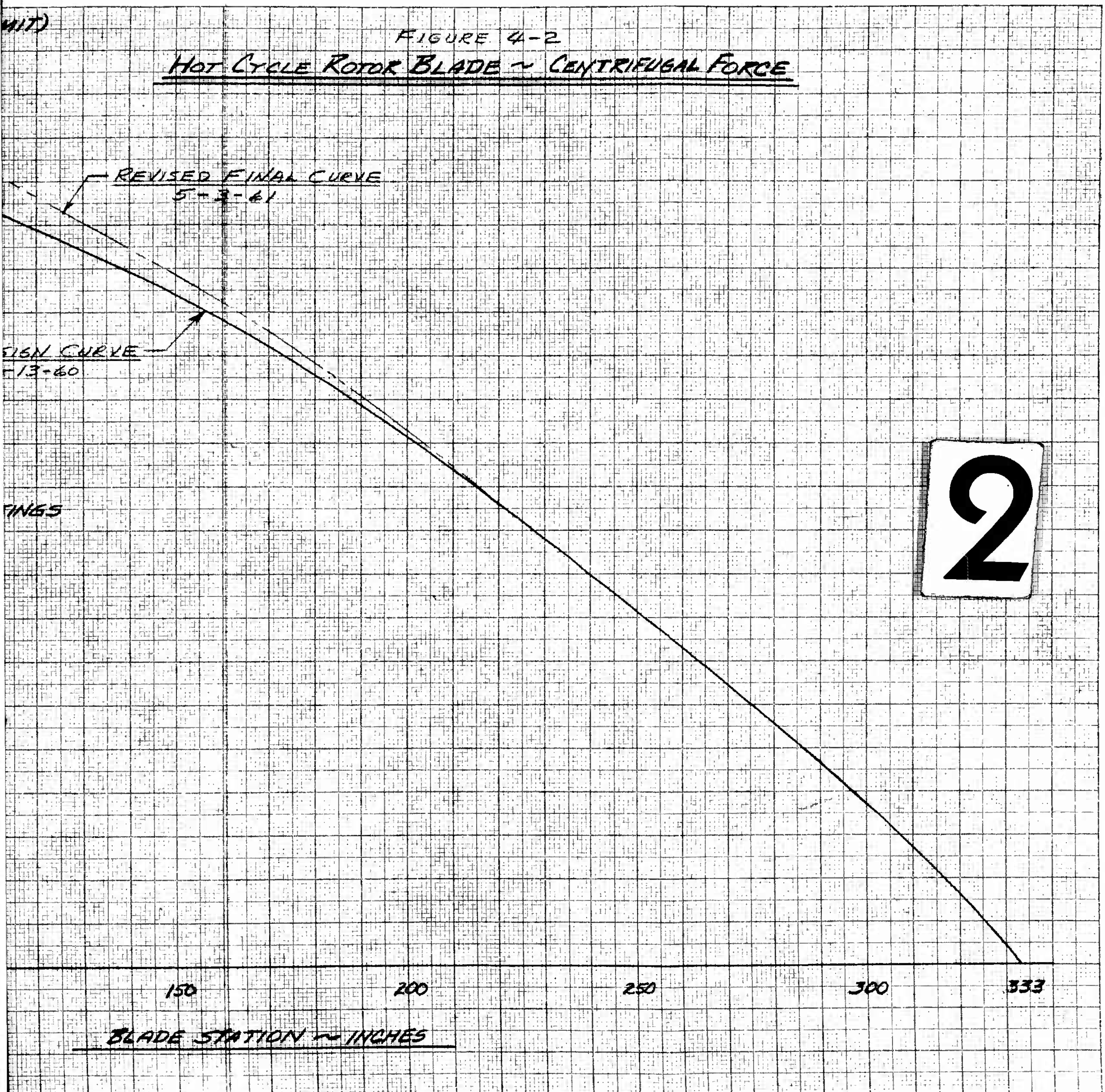


FIGURE 4-2
HOT CYCLE ROTOR BLADE ~ CENTRIFUGAL FORCE
(...NIT)
REVISED FINAL CURVE
5-3-61
...SIGN CURVE
...-13-60
...TINGS
150
200
250
300
333
BLADE STATION ~ INCHES

FLAPWISE MOMENT DISTRIBUTION - WEIGHTED FATIGUE CONDITION

The generalized force technique was used for the computation of cyclic mode shapes of bending moment, vertical shear, and stress for the hot cycle rotor blade in the modified approach to land (weighted fatigue) condition. This technique requires a knowledge of the individual equivalent tip loads which are forcing the blade to respond in each of its normal modes. The equivalent tip load for a given mode and harmonic number is given by the design thrust per blade multiplied by a non-dimensional thrust coefficient. The origin and value of all the thrust coefficients used in this analysis can be found in Reference (16), pages 53-57, and 111-117, particularly Table A6. Then, using an amplification factor given by Reference (17), page 64 (in this particular case assuming 10% damping present in the system), the tip deflection for harmonic motion of the blade is given by:

$$q_{nk} = \frac{G_{nk} \; F_{nk}}{(wy^2{}_n) \; w^2{}_n}$$

where:

q = tip deflection

G = equivalent tip load

F = amplification factor

m = blade running mass

y = normalized station deflection for a given mode shape

w = frequency of vibration

n = mode number

k = harmonic number

For this analysis, first and third harmonics of first and second mode bending were considered. This was based on a previous study which showed that the second harmonic loading did not increase the peak-to-peak cyclic load.

The phasing between the deflections caused by the first and third harmonics was handled as follows: Each harmonic for a given mode was resolved into its Cartesian components. The components for the first and third harmonics were added linearly and then the summed components were recombined vectorially to yield the total deflection for a given mode.

First and second mode shear and moment distribution for a unit tip of deflection were previously obtained by a Myklestad natural frequency analysis for the Hot Cycle Rotor System. Using the tip deflection computed by the generalized force technique, the corresponding distribution of shear for the first mode and second modes (V_1 and V_2) and corresponding distribution of bending moment for first mode and second mode (M_1 and M_2) were computed.

The generalized forces presented in Reference (16) yield the value of the largest single cycle of (e.g.) cyclic moment. It was then assumed that the value of the "full time" cyclic bending moment distribution, labelled as "Modified Approach to Land", which could be compared against the endurance limit for the blade was given by:

$$M = (3/4)\ M_2 + (3/4)\ M_2$$

and the shear distribution was given by:

$$V = (3/4)\ V_1 + (3/4)\ V_2$$

These shear and moment distributions ignore the coupling caused by the plane of the straps being different from the root chord plane. This coupling effect has the result that chordwise moments have a component which causes flapwise bending at the strap attach point. This is accounted for in an analysis based on tension beam theory. The final moment distribution is given in the curve of Figure 4-4.

ANALYSIS
PREPARED BY C. J. TIRMAN 24DEC59
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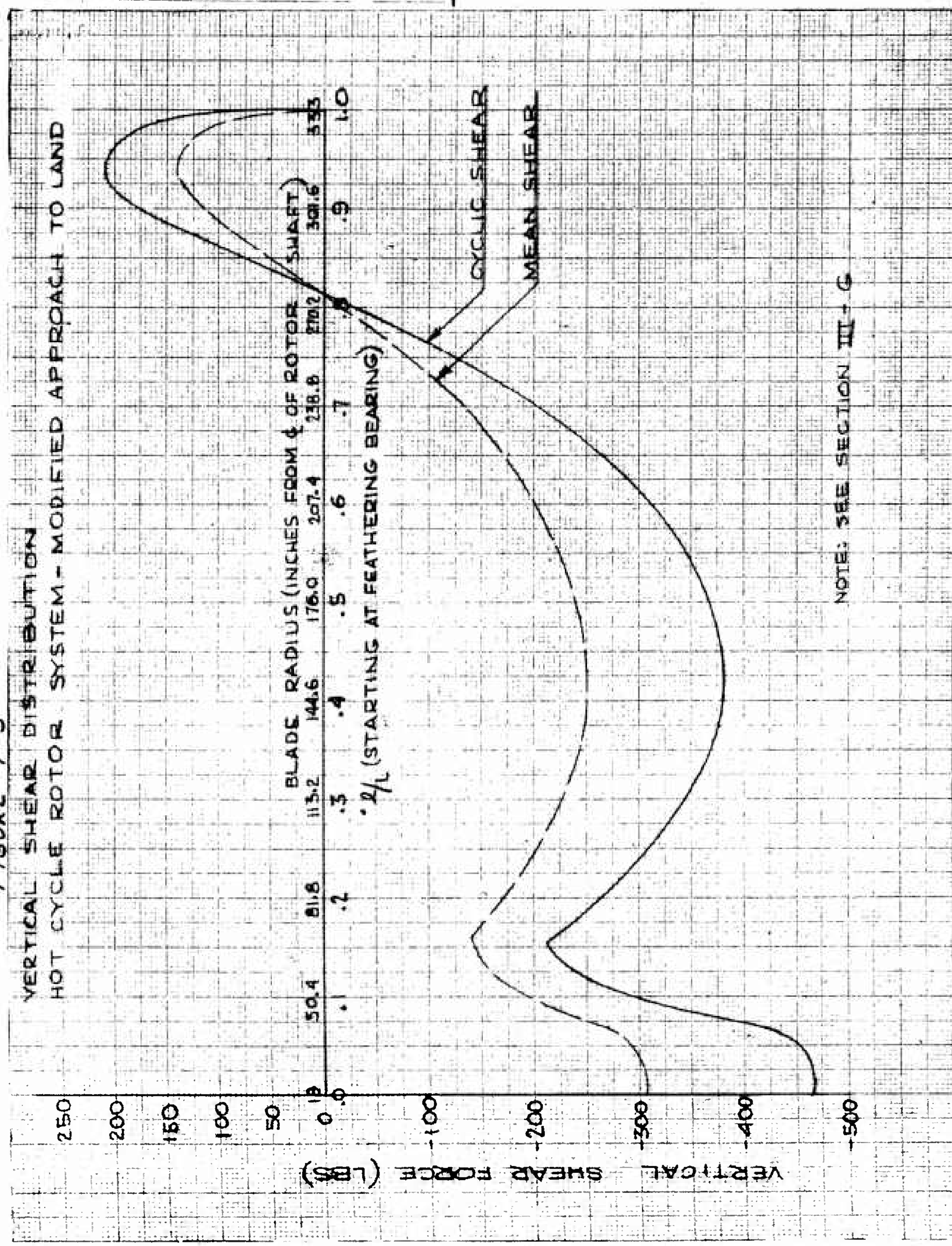

FIGURE 4-3
VERTICAL SHEAR DISTRIBUTION
HOT CYCLE ROTOR SYSTEM - MODIFIED APPROACH TO LAND

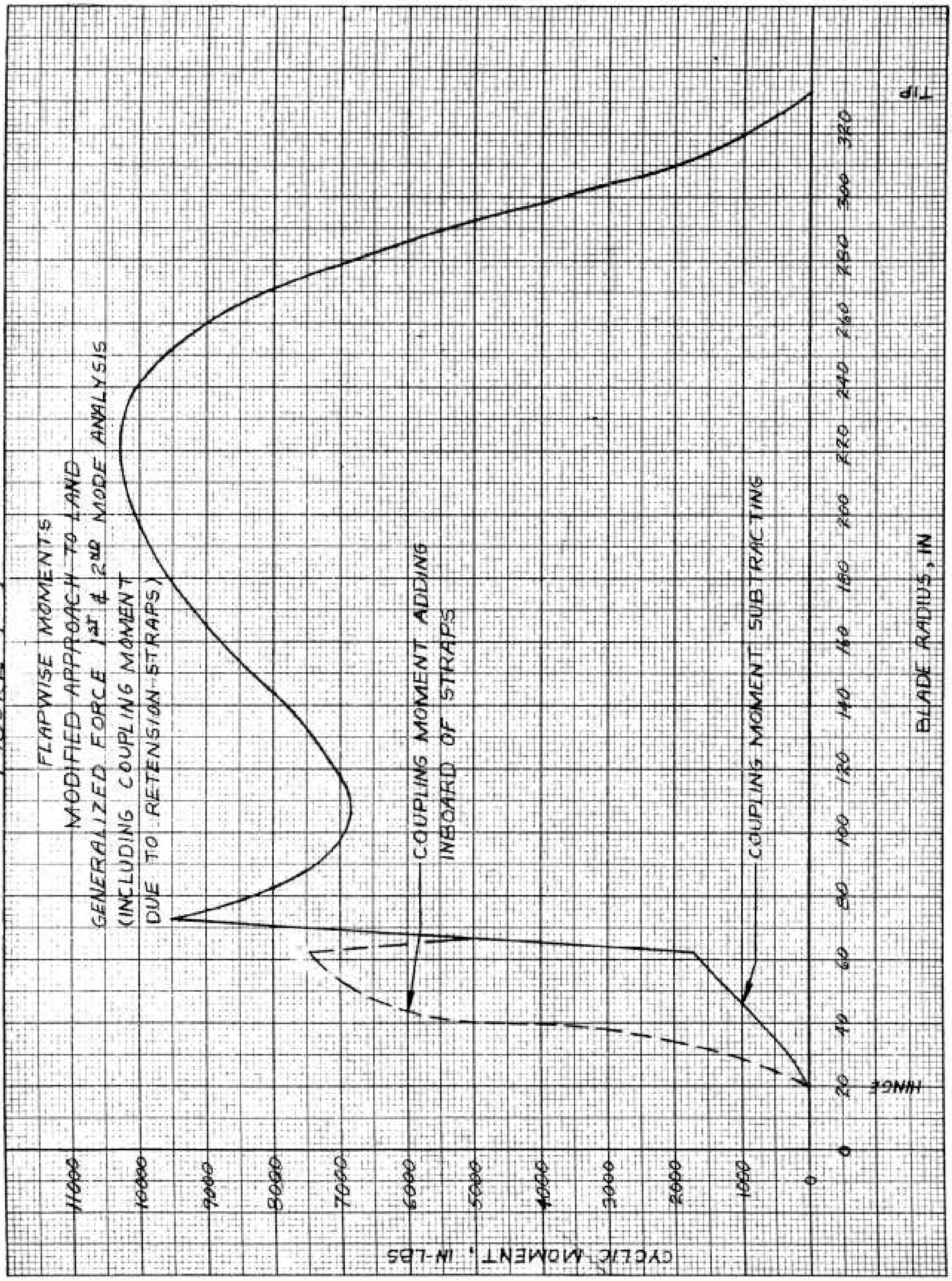

FIGURE 4-4

3-5-62

K+E 10 X 10 TO THE 1/2 INCH 359-11
KEUFFEL & ESSER CO.

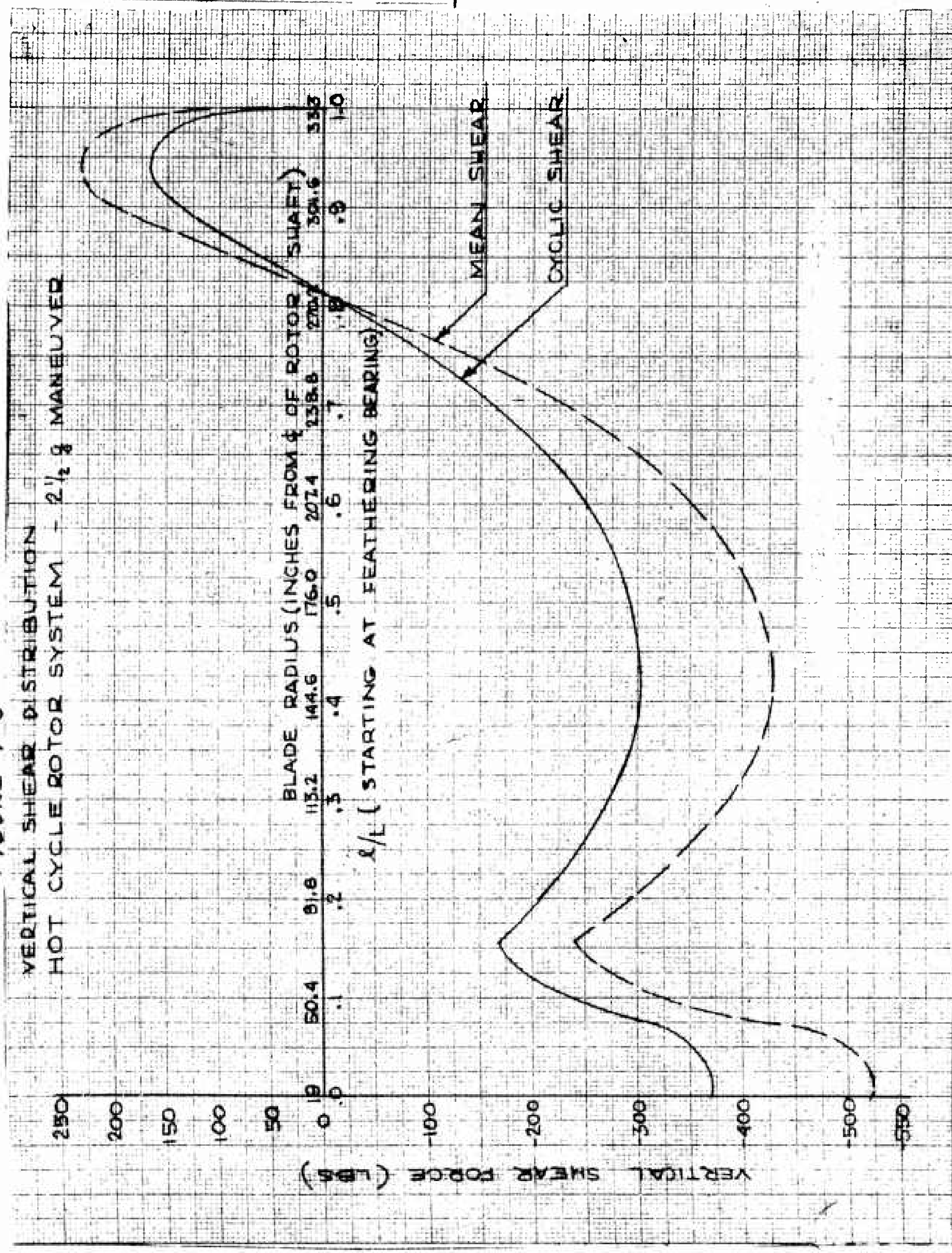

FIGURE 4-5
VERTICAL SHEAR DISTRIBUTION
HOT CYCLE ROTOR SYSTEM - 2½ g MANEUVER

ANALYSIS

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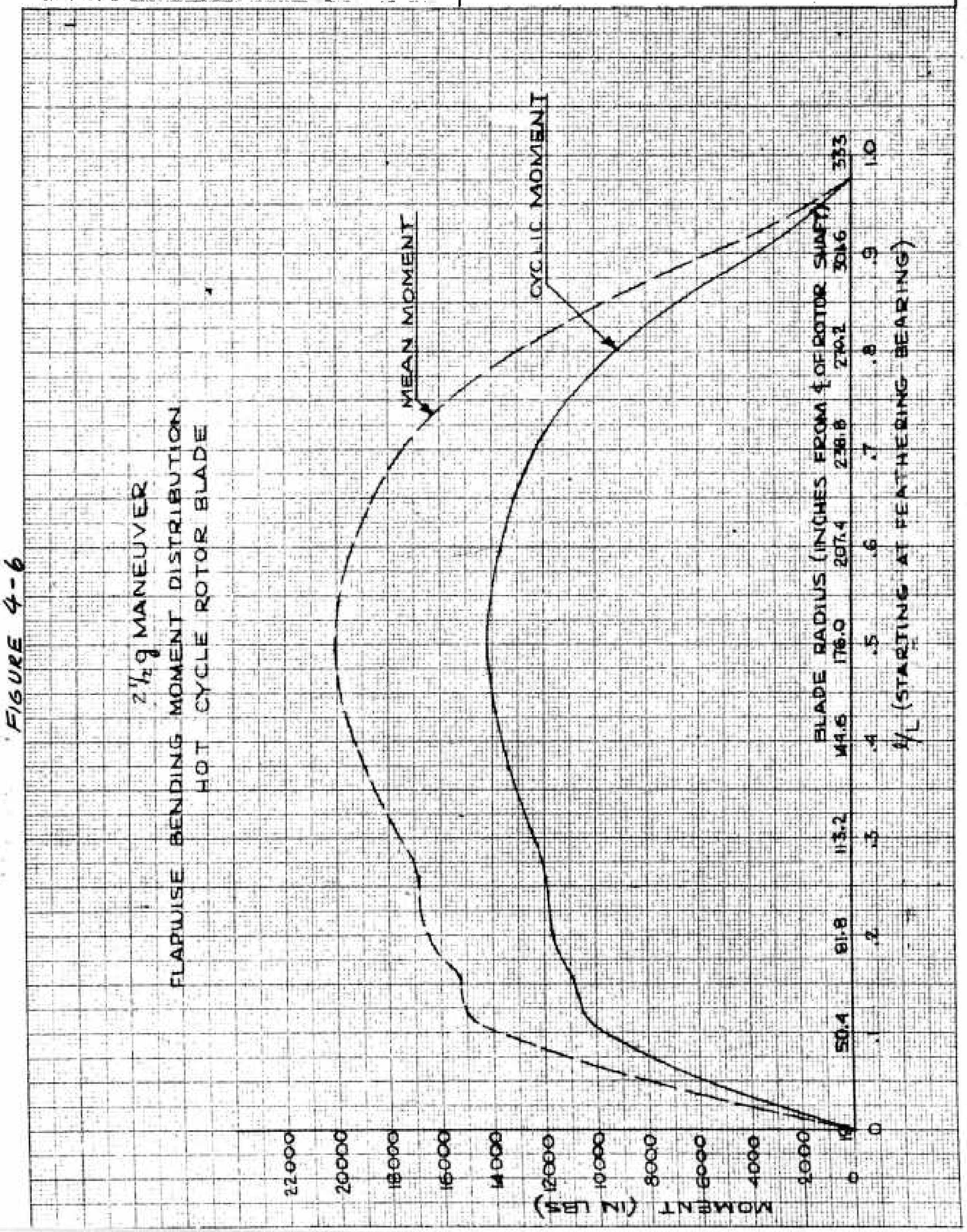


FIGURE 4-6

7 WEIGHTED FATIGUE CONDITION

a. BLADE SHEAR LOADS JUST OUTBD BLADE STRAP FITTINGS

200 ± 520 LB REF SECTION 1

b. BLADE BENDING MOMENTS - CHORDWISE

± 82,100 IP LIMIT REF SECTION 1

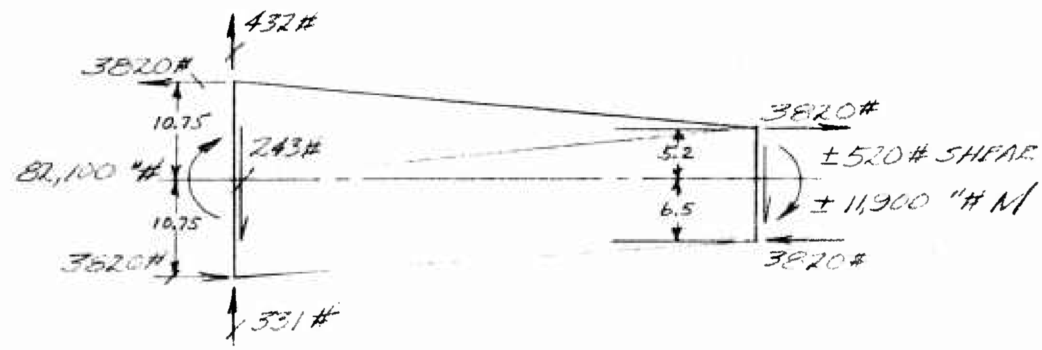
GIVEN AT THE FEATHERING BEARING AT THE ANGLE OF CONING AND IN THE PLANE OF ROTATION.

c. CENTRIFUGAL FORCE

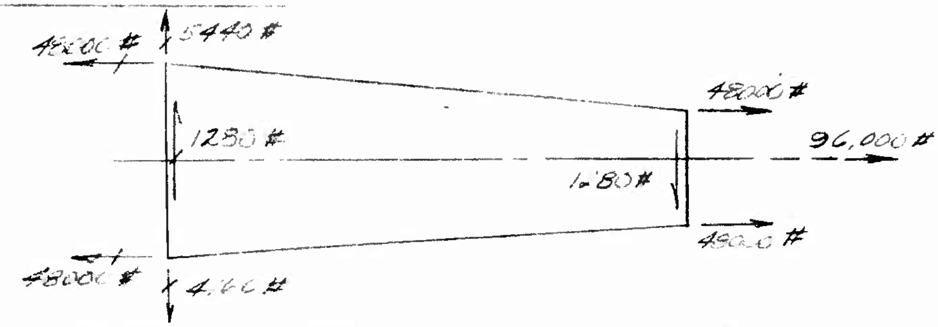
C.F. = 95,260 LBS

d. LOADS BREAKDOWN

1. CHORDWISE SHEAR AND BENDING



2. CENTRIFUGAL FORCE



CHORDWISE SHEAR & BENDING MOMENTS

II. 2½g MANEUVER CONDITION

a. BLADE LOADS JUST OUTB'D BLADE STRAP FITTINGS

100 ± 1550 LB REF SECTION 1

b. BLADE BENDING MOMENTS - CHORDWISE

± 253,000 IP LIMIT REF SECTION 1

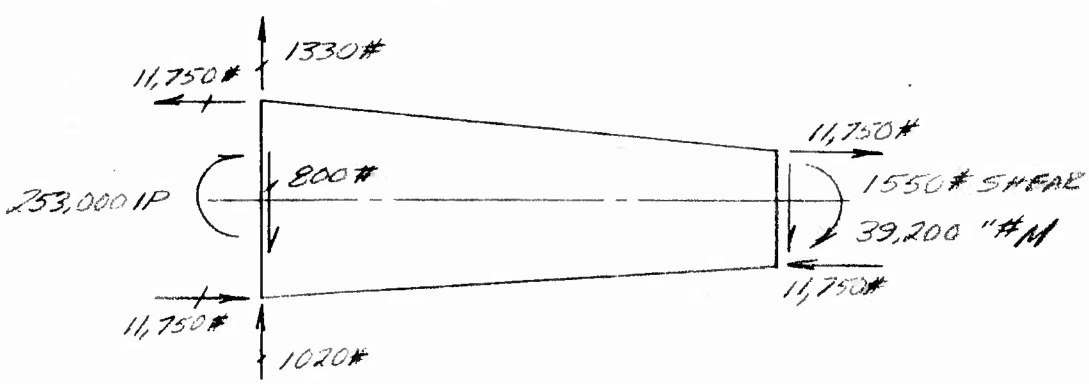
GIVEN AT ETC. - SEE PREVIOUS PAGE

c. CENTRIFUGAL FORCE

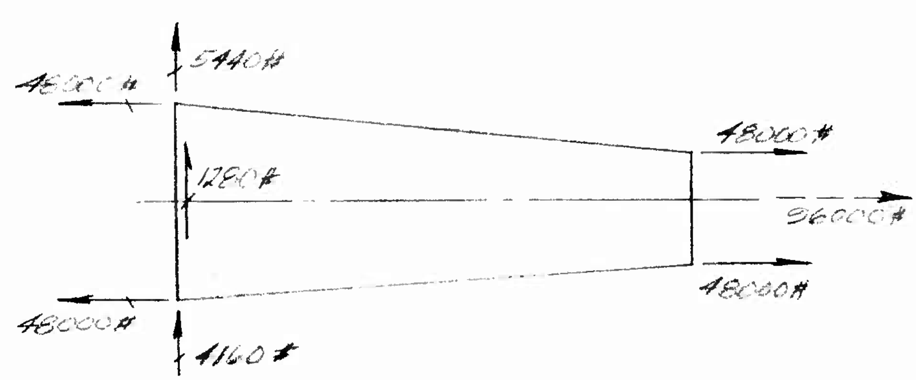
C.F. = 95,260#

d. LOADS BREAKDOWN

1. CHORDWISE SHEAR AND BENDING



2. CENTRIFUGAL FORCE



HUGHES TOOL COMPANY-AIRCRAFT DIVISION

ANALYSIS HOT CYCLE BLADE MODEL 285 REPORT NO. 285-13 PAGE 42.13

PREPARED BY L. L. ERLE 12-31-59

CHECKED BY

BLADE TORSION LOADS

I. WEIGHTED FATIGUE CONDITION

a. BLADE TORSION LOAD

13,100 ± 25,140 IP LIMIT REF SECTION 1

b. STRAP TORSION

0 ± 17,800 IP LIMIT

c. CYCLIC AIR LOAD TORSION

25,140 − 17,800 = 7340 IP LIMIT

II. 2½ G MANEUVER CONDITION

a. BLADE TORSION LOAD

20,170 ± 32,300 IP LIMIT REF SECTION 1

b. STRAP TORSION

9480 ± 28,600 IP LIMIT

c. MOMENT BREAKDOWN

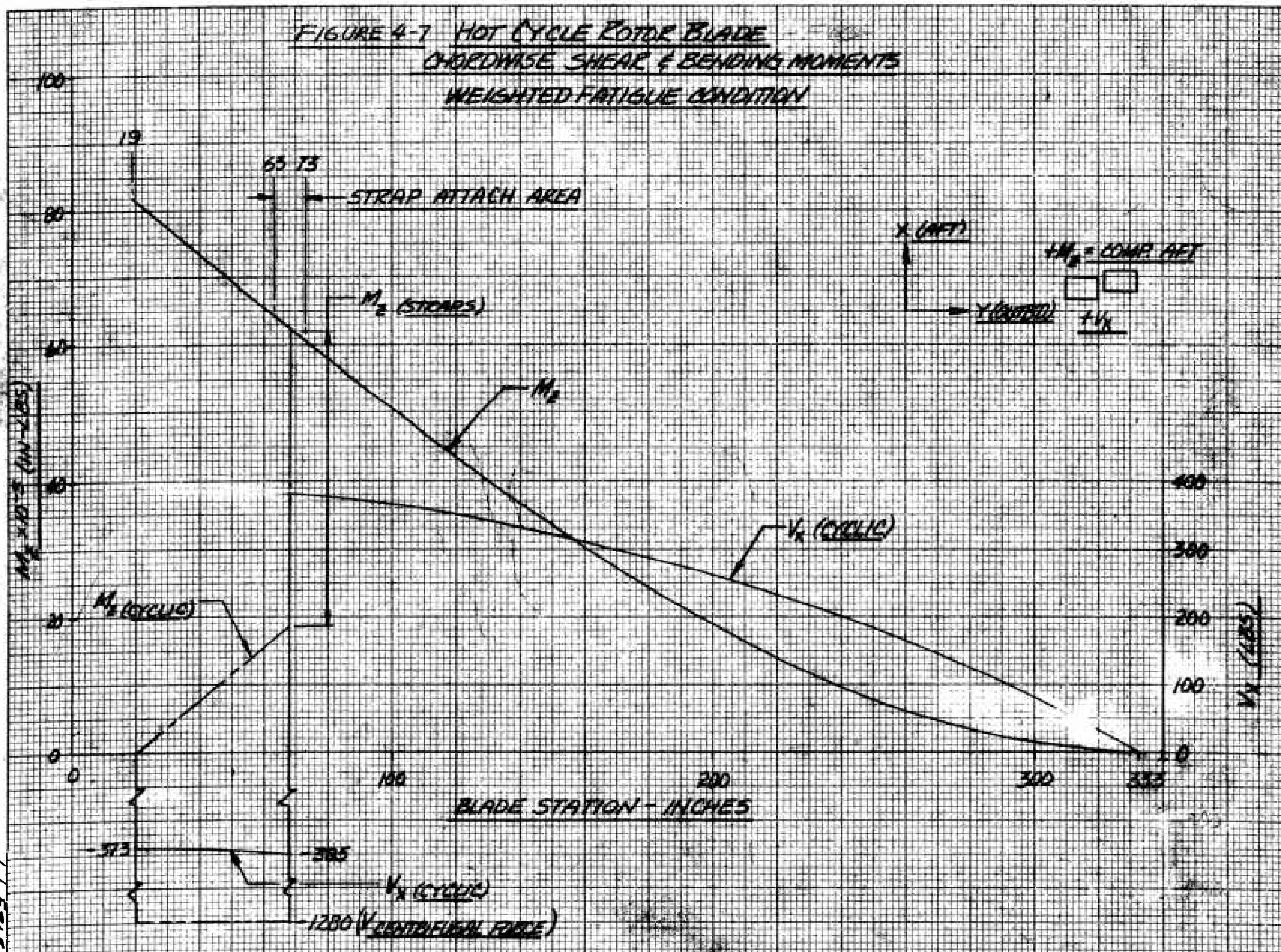
20,170 IP = STEADY TORSION

20,170 + 32,300 = 52,470 IP = MAX TORSION

52,470 − 28,600 = 23,870 = TOTAL BLADE TORSION

9704

PG. 4.2.14



L.L. EZLE
5-6-60

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BOSTON 10, MASS.
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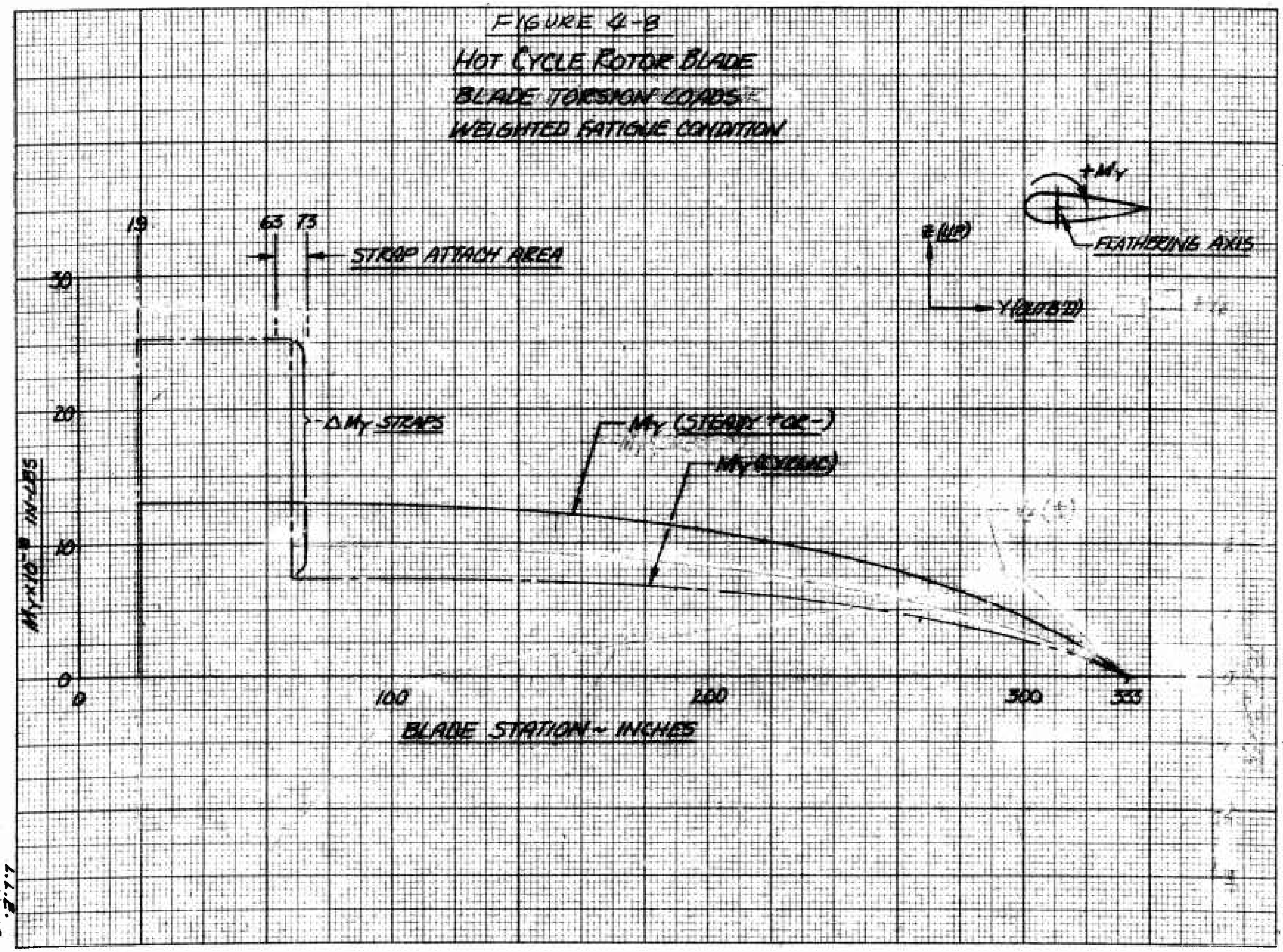

FIGURE 4-8
HOT CYCLE ROTOR BLADE
BLADE TORSION LOADS
WEIGHTED FATIGUE CONDITION

L.L.E.
12-31-59

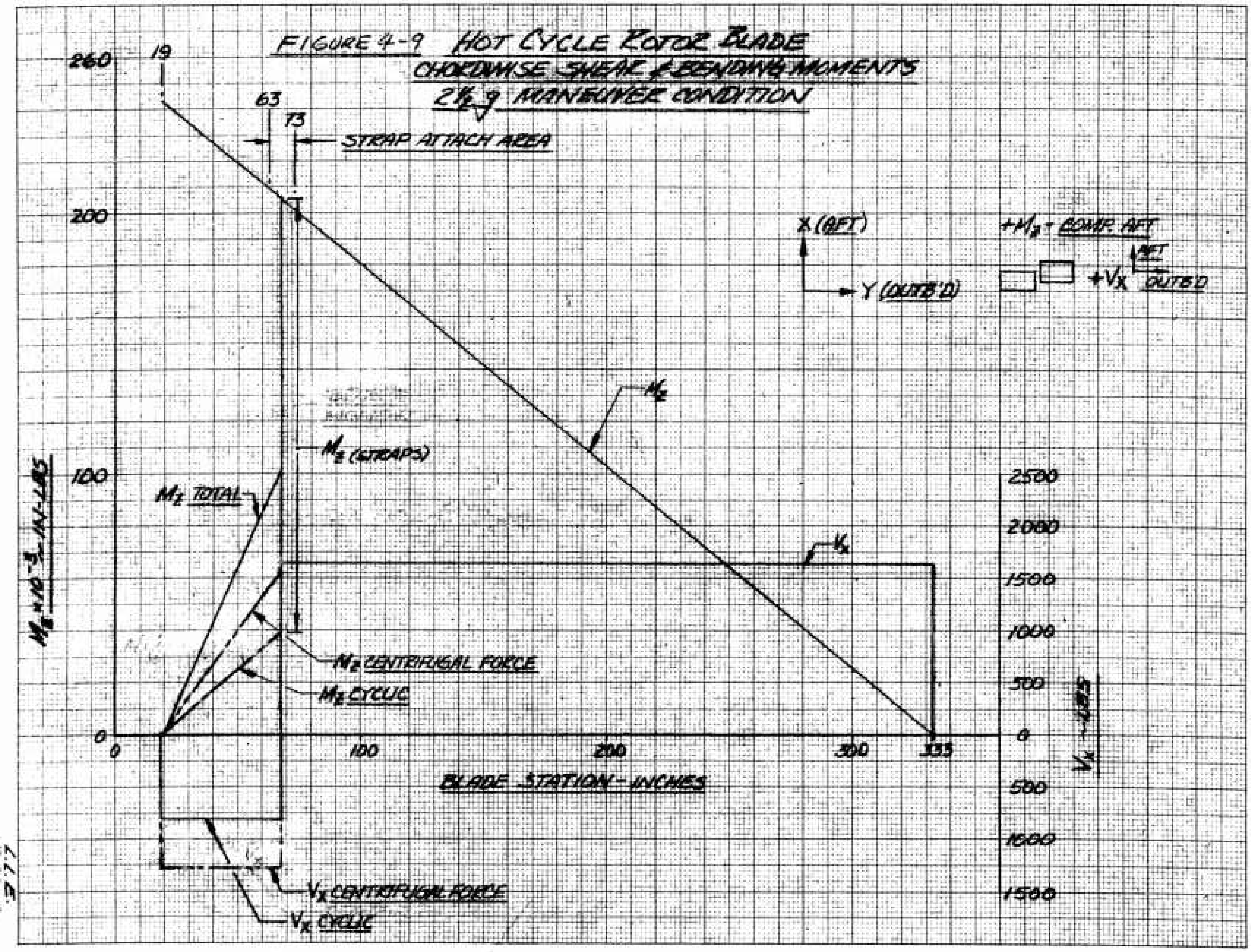

FIGURE 4-9 HOT CYCLE ROTOR BLADE
CHORDWISE SHEAR & BENDING MOMENTS
2½ g MANEUVER CONDITION

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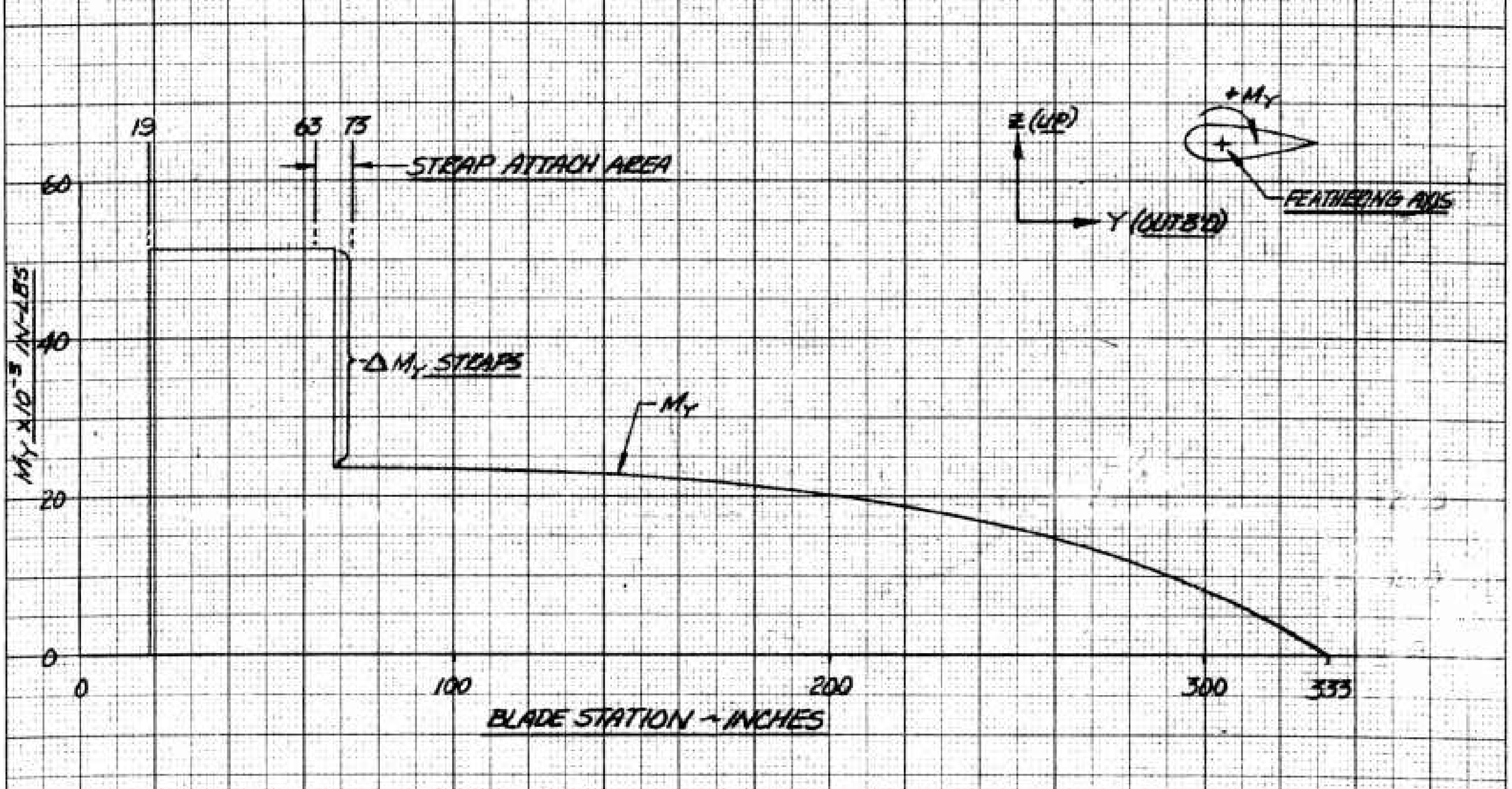
FIGURE 4-10 HOT CYCLE ROTOR BLADE
BLADE TORSION LOADS
2½ g MANEUVER CONDITION



L.L.E.
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HUGHES TOOL COMPANY - AIRCRAFT DIVISION

ANALYSIS Hot Cycle Rotor MODEL 285 REPORT NO. 285-13 PAGE 42.18

PREPARED BY L. L. Erle

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CHORDWISE PRESSURE DISTRIBUTION
LEVEL FLIGHT CRUISE CONDITION,
MAXIMUM LIFT

REF REPORT No 285-7 FIG 25; Pg 51

TABLE 4.2-3

X/C	P_u	$1.16\,P_u$	P_l	$1.16\,P_l$	P_T	$1.16\,P_T$
0	—	—	—	—	—	—
.015	-2.75	-3.19	1.80	2.09	4.55	5.28
.025	-3.12	-3.62	1.40	1.62	4.47	5.19
.050	-3.26	-3.78	.73	.85	3.90	4.52
.100	-2.90	-3.36	.20	.23	2.87	3.33
.200	-2.33	-2.70	-.26	-.30	1.90	2.20
.300	-1.90	-2.20	-.46	-.53	1.40	1.62
.400	-1.50	-1.75	-.50	-.58	1.06	1.23
.500	-1.15	-1.33	-.42	-.49	.82	.95
.600	-.84	-.97	-.29	-.34	.62	.72
.700	-.55	-.64	-.14	-.16	.45	.52
.800	-.23	-.27	0	0	.29	.34
.900	+.10	+.12	.24	.28	.14	.16
1.00	+.56	+.65	.56	.65	0	0

FORM 9706

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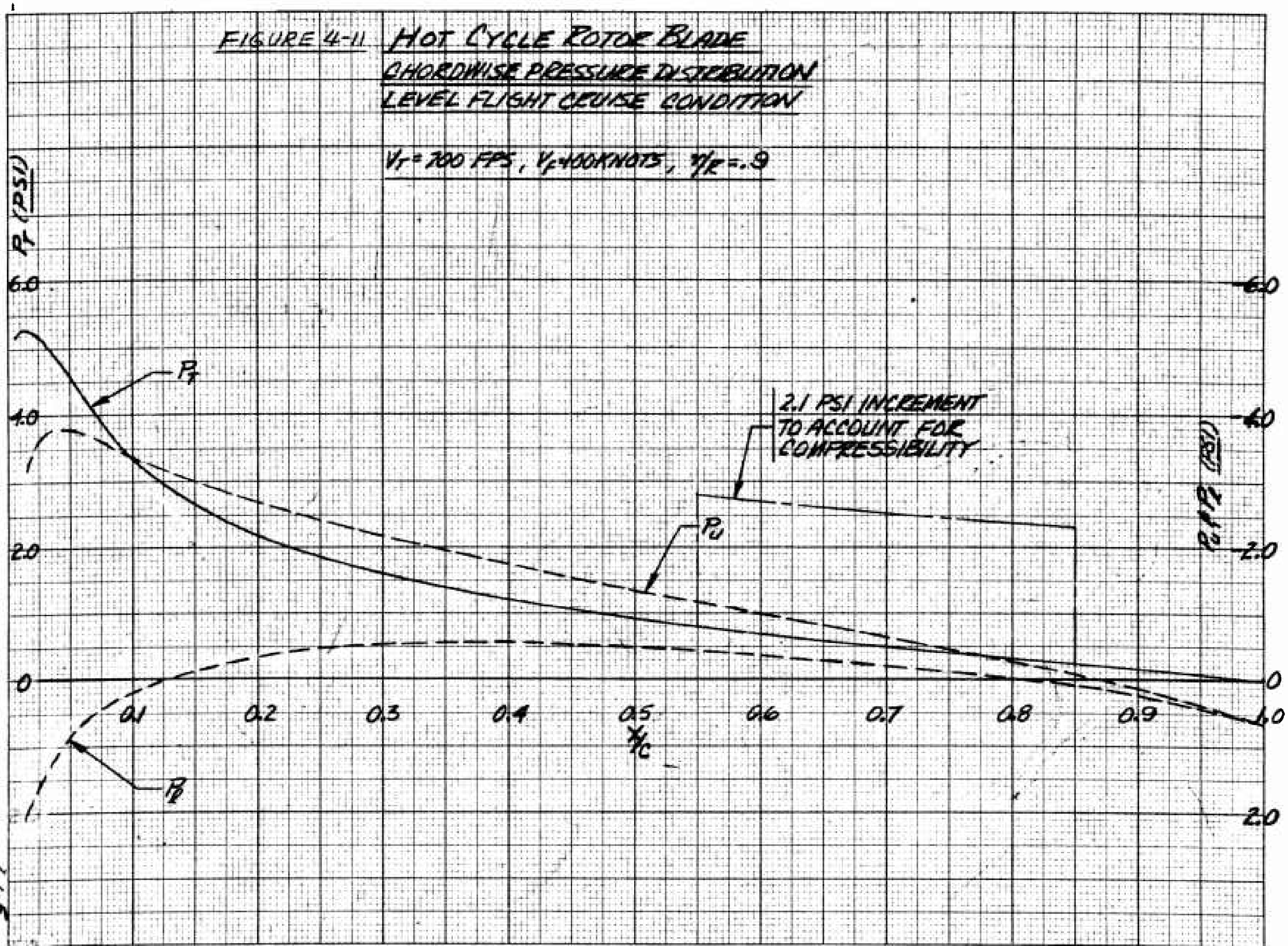
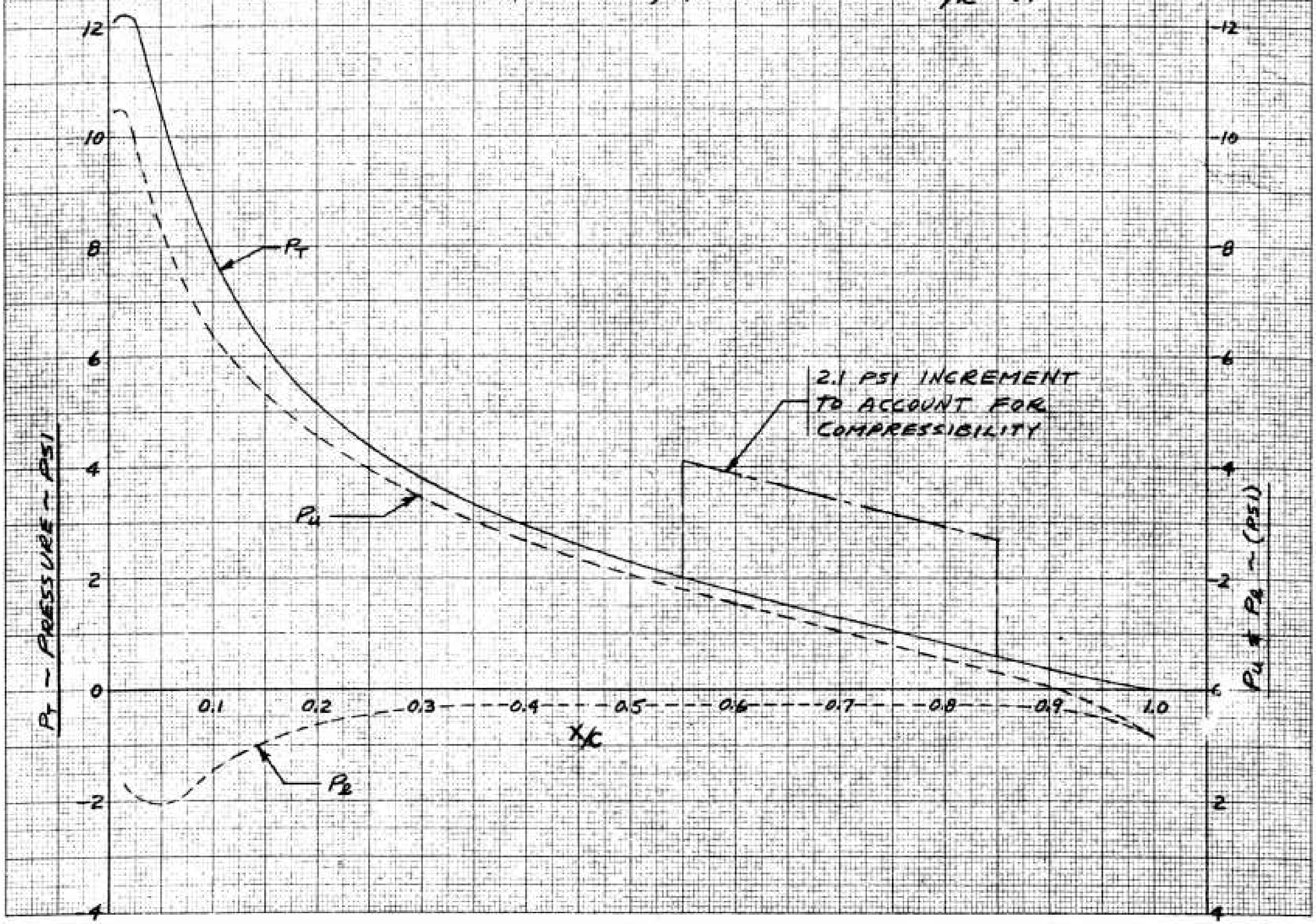


L.L.E. 1-13-60

K+E 10 X 10 TO THE CM. 359-14
KEUFFEL & ESSER CO. MADE IN U.S.A.

FIGURE 4-12
CHORDWISE PRESSURE DISTRIBUTION ~ 2.5g MANEUVER
V_T - 700 FPS, V_F = 100 KNOTS   r/R = .9

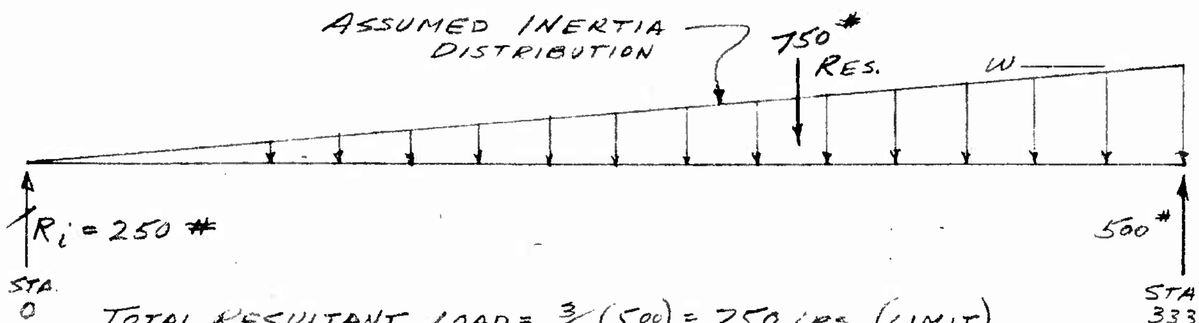


CRS
12-17-59

ROTOR STARTING CONDITION

STATIC THRUST = 500 LB./BLADE (MAX.) APPLIED AT TIP

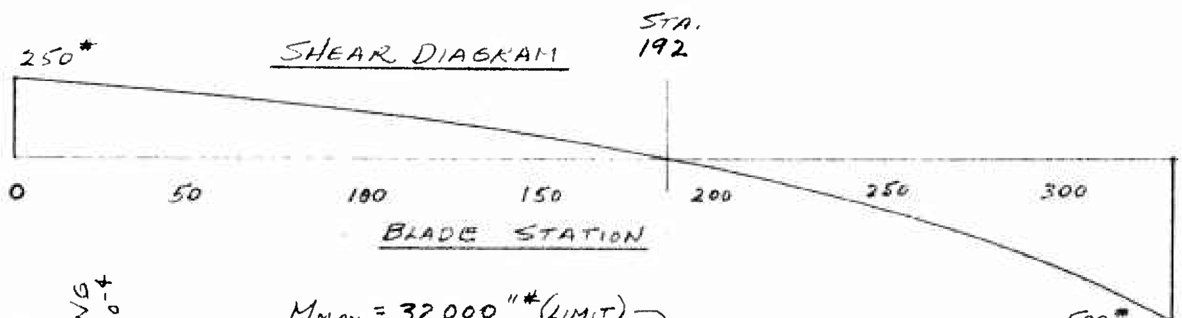
REACTED BY ROTATIONAL INERTIA. (REF. SECTION 1)

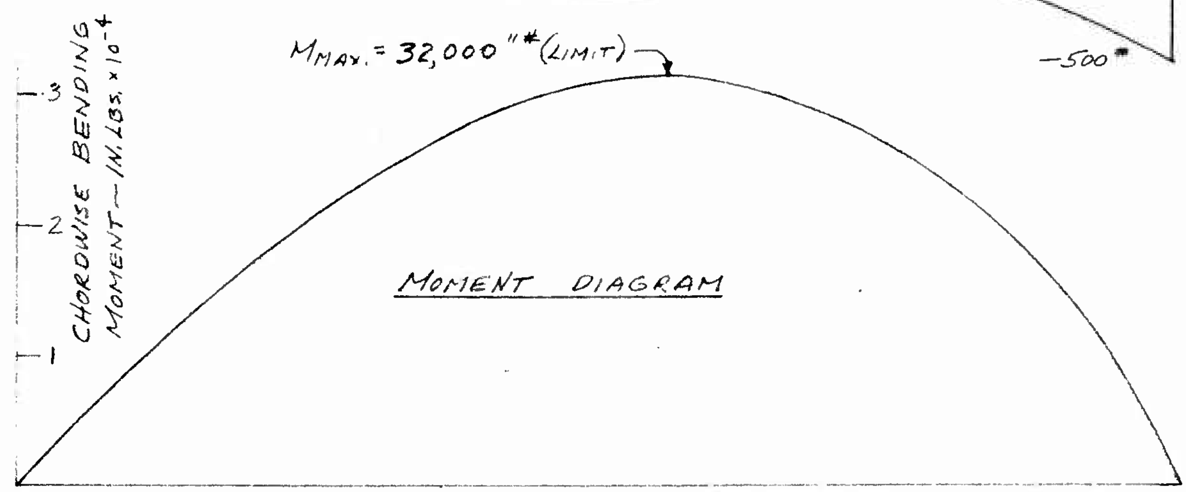


TOTAL RESULTANT LOAD = $\frac{3}{2}(500)$ = 750 LBS. (LIMIT)

$R_i = 750 - 500 = 250$ LBS.

$w = \frac{2(750)}{333} = 4.50$ #/IN.





HUGHES TOOL COMPANY - AIRCRAFT DIVISION

ANALYSIS HOT CYCLE BLADE MODEL 285 REPORT NO. 285-13 PAGE 4.2.22

PREPARED BY L.L. ERLE 1-4-60

CHECKED BY

GROUND FLAPPING CONDITION

TABLE 4.2-4 SPANWISE SHEAR & MOMENT DISTRIBUTION (LIMIT, $n_z = 2.5$)

* REF BLADE SPANWISE WEIGHT DISTR. (SECTION 3)

STATION	(1) ΔY	(2) * w_{AVG}	(3) $2.5 w_{AVG}$	(4) W (1)×(3)	(5) V	(6) V_{AVG}	(7) ΔM (1)×(6)	(8) M	(9)
270-333	63	0.890	2.225	140.18		70.08	4415		
					140.18			4415	
210-270	60	0.949	2.371	142.26		211.31	12,680		
					282.44			17,095	
150-210	60	1.006	2.514	150.84		357.86	21,470		
					433.28			38,565	
91-150	59	1.062	2.655	156.65		511.60	30,185		
					589.93			68,750	
73-91	18	1.31	3.275	58.95		619.41	11,150		
					648.88			79,900	
63-73	10	4.24	10.600	106.00		701.88	7020		
					754.88			86,920	
60-63	3	1.33	3.325	9.98		759.87	2280		
					764.86			89,200	
49-60	11	1.22	3.050	33.55		781.68	8600		
					798.41			97,800	
42-49	7	1.97	4.925	34.48		815.65	5710		
					832.89			103,510	
33-42	9	0.80	2.000	18.00		841.89	7575		
					850.89			111,085	
19-33	14	2.67	6.675	93.45		897.61	12,565		
					944.34			123,650	
STRAPS	49	17.64	44.10	—	44.10	44.10	2160		
(19-68)		(w/2)			@ STA 68			125,810	

FORM 9707

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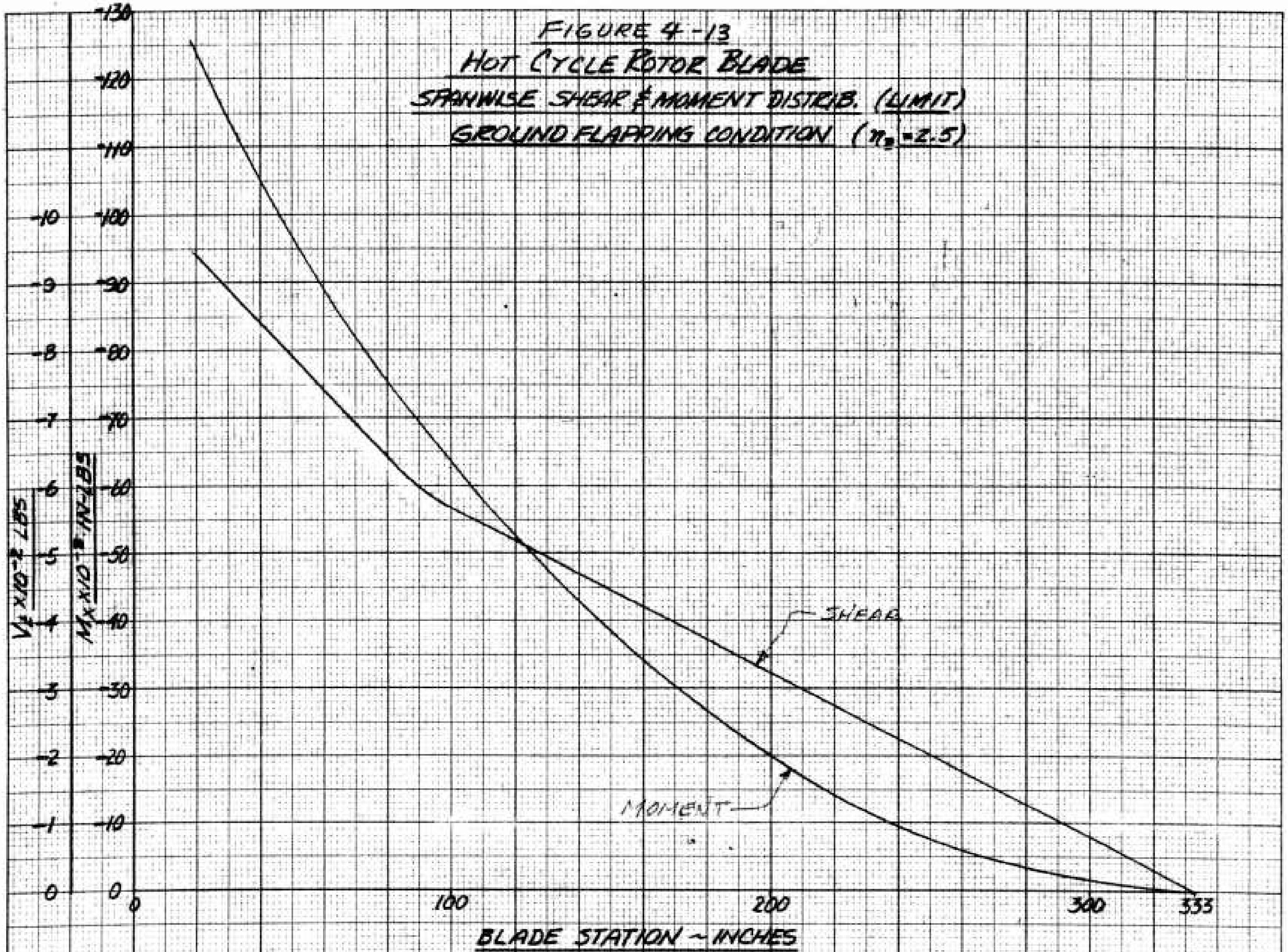


L.I.E. 1-5-60

4.3 HUB AND SHAFT LOADS

LOADS ON THE HUB AND SUPPORTING SHAFT COME FROM THREE SOURCES: (1) ROTOR LIFT, (2) CONTROL SYSTEM AND (3) DUCT PRESSURE.

CONDITIONS INVESTIGATED ARE (1) WEIGHTED FATIGUE, (2) 2½ G MANEUVER AND (3) GROUND FLAPPING. THE FLAT PITCH OVER-REV CONDITION IS NOT CRITICAL IN THE HUB AND SHAFT AREA EXCEPT IN THE STRAP ATTACH REGION AND HUB CARRY-THROUGH STRUCTURE. BASIC PARAMETERS, LOAD FACTORS, TILT ANGLES, ETC., ARE OBTAINED FROM SECTION 1.

THE ROTOR HUB IS ATTACHED TO THE SHAFT BY A GIMBAL ARRANGEMENT AT WATERLINE +4.25. HUB AND SHAFT ROTATE WITH THE BLADES. THE SHAFT IS MOUNTED TO THE PYLON SUPPORTING STRUCTURE THRU BEARINGS AT W.L. -8.25 AND W.L. -36.95. SIDE LOADS AND MOMENTS ARE REACTED AS RADIAL LOADS IN THE UPPER AND LOWER BEARINGS WHILE LIFT OR THRUST LOADS ARE REACTED ENTIRELY BY THE LOWER BEARING.

HUB & SHAFT LOADS

(REF. DWGS. 285-0500, 285-0517)

ROTOR LIFT LOADS

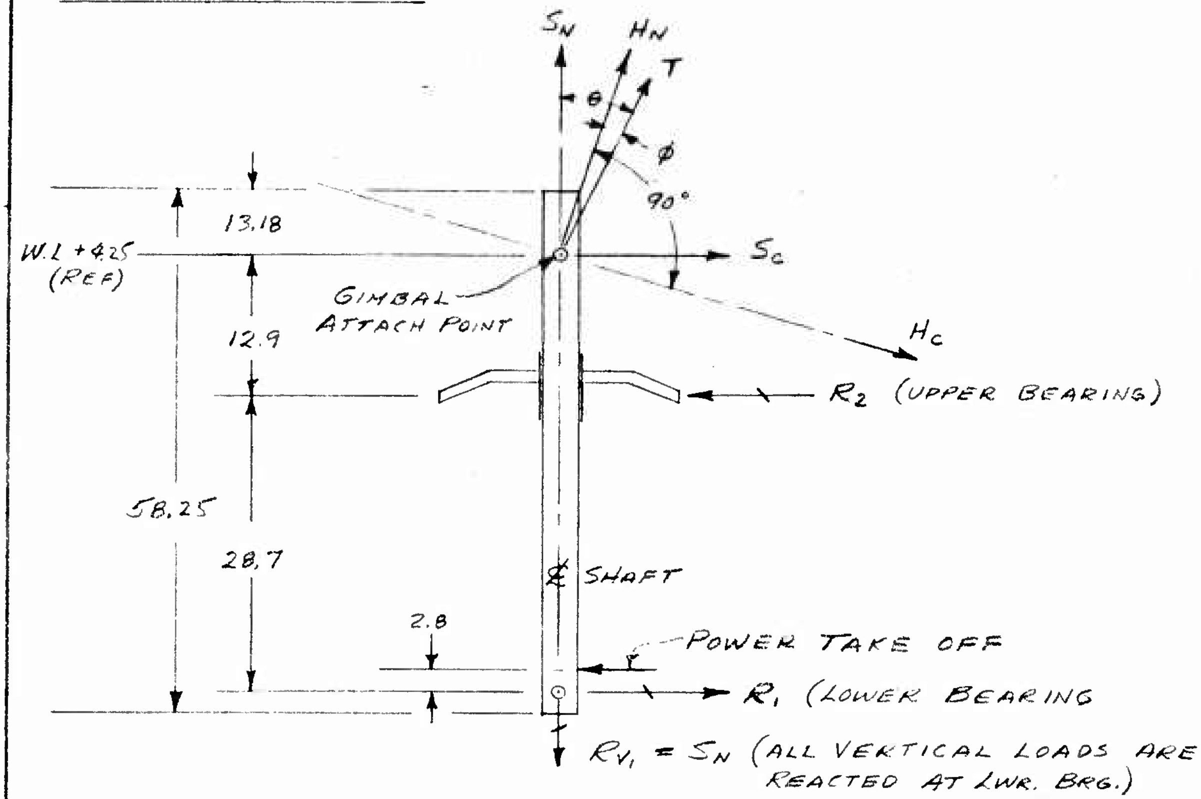


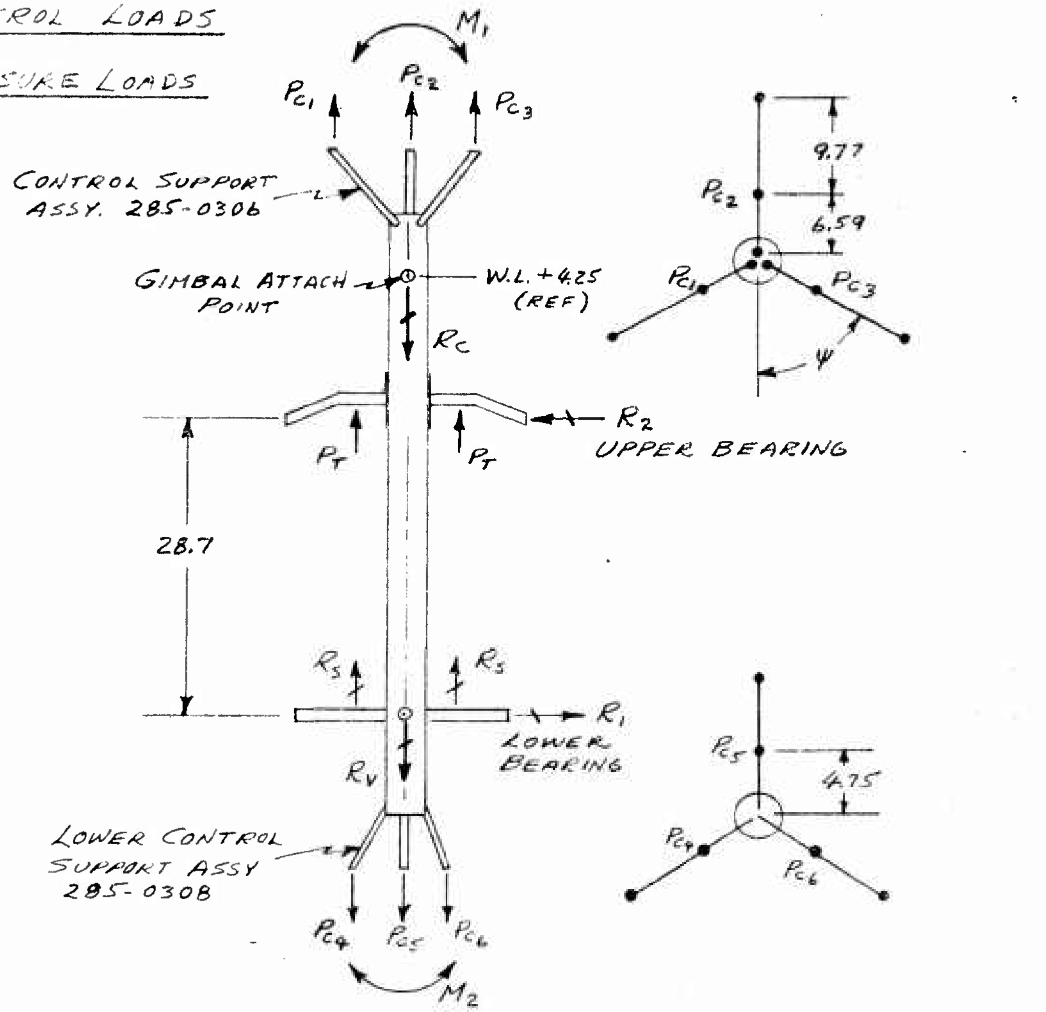
TABLE 4.3-1 ROTOR LOADS SUMMARY

CONDITION	θ (1)	φ (1)	T (1)	HUB LOADS		SHAFT LOADS				
				H_N	H_C (2)	S_N	S_C	PTO (3)	R_1	R_2
2½ G MANEUVER	10°	2°	38,840	38,800	±3675	38,250	±6740	±6480	±8880	±9770
WEIGHTED FATIGUE	6°	1°	15,380	15,360	±1050	15,300	±1610	±4320	±4620	±2330
"			22,950	22,950	±1050	22,950	±1610	±4320	±4620	±2330
2½ G GROUND FLAPPING	—	—	—	—	—	—	9700	—	4360	4360

NOTES: (1) REF. SECTION 1.
(2) H_C INCLUDES IN PLANE SHEAR COMPONENT
(3) ARBITRARY POWER REQUIREMENTS:
2½ G MANEUVER = 150 HP
CRUISE CONDITION = 100 HP

HUB & SHAFT LOADS

CONTROL LOADS & PRESSURE LOADS



NOTES:

$P_{C_1}, P_{C_2}, P_{C_3}$ = FORCES FROM CONTROLS ON UPPER END OF SHAFT

$P_{C_4}, P_{C_5}, P_{C_6}$ = FORCES FROM CONTROLS ON LOWER END OF SHAFT

P_T = TENSION LOAD DUE TO DUCT PRESSURE (INCLUDES FACTOR OF 1.33)

R_C = CONTROL REACTION FROM HUB

R_S = REACTION FROM CONTROL CYLINDERS THRU STRUCTURE TO LOWER BEARING

HUB & SHAFT LOADS

CONTROL LOADS (CONT'D.)

TABLE 4.3-2 CONTROL & PRESSURE LOADS SUMMARY

CONDITION	P_{C_1}	P_{C_2}	P_{C_3}	P_{C_4}	P_{C_5}	P_{C_6}	M_1	M_2
WEIGHTED FATIGUE	2030 ± 2150	2030 ∓ 4300	2030 ± 2150	2610 ± 2765	2610 ∓ 5530	2610 ± 2765	42,390	39,400
2½ G MANEUVER	3310 ± 2645	3310 ∓ 5290	3310 ± 2645	4280 ± 3420	4280 ∓ 6840	4280 ± 3420	52,290	48,750

CONDITION	P_T	R_C	R_S	R_V	R_1	R_2
WEIGHTED FATIGUE	8660	2460	4200	8660	104	104
2½ G MANEUVER	8660	3990	6900	8660	122	122

SECTION 5

STRUCTURAL ANALYSIS

CONTENTS

5. 1 INTRODUCTION

Structural Analysis of the Hot Cycle Rotor gives analytical substantiation of the design for the effects of both loads and temperatures. Analysis of the structural components is based on design flight loads and operating temperatures as delineated in Sections 1 and 4 The Rotor Blade Structural Analysis is contained in Volume II and the Hub and Control System Analysis, in Volume III. A summary of minimum margins of safety is presented in Section 5. 2, following.

Additional substantiation of the structural integrity of the rotor components is afforded by the successful completion of 60 hours of whirl testing (See HTC-AD Report 285-16) and two million cycles of fatigue testing of the rotor blade (See HTC-AD Report 285-9-8).

5.2 SUMMARY OF MINIMUM MARGINS OF SAFETY

ITEM	DWG. NO.	LOADING	MARGIN OF SAFETY	PAGE NO.
ROTOR BLADE	285-0100			
Front Blade Spar	285-0170	Bending Fatigue	.40	5.2.2.13
Front Blade Spar	-0170	Bending & Tension	.48	5.2.2.17
Rear Blade Spar	-0170	Bending Fatigue	.18	5.2.2.10
Rear Blade Spar	-0170	Bending & Tension	.04	5.2.2.16
Doubler Inst'l	-0200	Shear	.08	5.2.2.23
Blade Retention Straps	-0121	Tension & Bending	.03	5.2.3.16
Segment Ass'y Aft	-0117	Compression	.08	5.2.4.10
Segment Ass'y Rib	-0113	Thermal & Bending	.48	5.2.4.13
Segment Ass'y Attach	-0113	Bearing	.01	5.2.4.16
Basic Flexure	-0199	Bending Fatigue	0	5.2.4.27
Tip Cascade	-0172	Thermal	.02	5.2.5.7
Tip Main Segment	-0171	Thermal & Bending	.01	5.2.5.10
Segment Flexure	-0138	Bending Fatigue	.30	5.2.6.15
Rib Sta. 63.0	-0128	Tension & Bending	.09	5.2.7.13
Rib Sta. 73.0	-0129	Tension & Bending	.01	5.2.7.20
Blade Skin Top	-0139	Bearing	.26	5.2.7.23
Blade Web	-0139	Compression	.08	5.2.7.24
Door	-0139	Bearing	.24	5.2.7.25
Strap Attach Fitting	-0164	Bearing	.03	5.2.7.28

SUMMARY OF MINIMUM MARGINS OF SAFETY

ITEM	DWG. NO.	LOADING	MARGIN OF SAFETY	PAGE NO.
Blade Structure Sta. 33 to 63	285-0166	Bearing Fatigue	. 02	5. 2. 8. 9
Ring Flexure	-0197	Bending	. 03	5. 2. 8. 25
Rib Sta. 24. 25	-0190	Bending	. 72	5. 2. 9. 2. 16
Rib Sta. 33. 25	-0135	Bending Fatigue	. 29	5. 2. 9. 3. 9
Rib Sta 33. 25	-0135	Bearing Fatigue	. 11	5. 2. 9. 4. 1
Feathering Arm	-0140	Bearing	. 15	5. 2. 9. 5. 1
Rib Sta. 24. 25	-0190	Bending	. 28	5. 2. 9. 8. 5
Spar Attachment	-0127	Shear	. 11	5. 2. 9. 9. 0
Panel Web	-0127	Shear	. 05	5. 2. 9. 10. 0
Panel Fasteners	-0127	Shear	0	5. 2. 9. 11. 5
Feathering Bearing Ball	-0126	Bending	. 60	5. 2. 9. 13. 5
Inboard Duct	-0179	Tension	. 42	5. 2. 10. 5
Support Bracket	-0131	Bearing	. 17	5. 2. 10. 13
Flexure Sta. 15. 5	-0178	Bending Fatigue	0	5. 2. 10. 21
Outboard Duct	-0132	Thermal & Bending	0	5. 2. 10. 26
Turnbuckle Ass'y	-0194	Tension	. 08	5. 2. 10. 36
Duct Assembly Frame Sta. 83	-0132	Compression	. 19	5. 2. 10. 44

ROTOR HUB

ITEM	DWG. NO.	TYPE LOADING	MIN M. S.	PAGE NO.
Hub Assembly	285-0511	See Individual Items Below		
Upper & Lwr Strap	285-0564	Tension	. 44	5. 3. 2. 3. 0
Plates	285-0565	Tension (Fatigue)	1. 44	5. 3. 2. 4. 5
Side Web	285-0566	Attachments	. 38	5. 3. 2. 6. 0
Upper Beam Angle	285-0570	Column	. 75	5. 3. 2. 7. 0
Inter-Beam Fitting	285-0562	Attachments	. 05	5. 3. 2. 8. 1
Splice Fitting	285-0563	Attachments	. 75	5. 3. 2. 11. 0
Gimbal Fitting	285-0529	Shear	1. 60	5. 3. 2. 12. 2
Tilting Hub Ring	285-0532	Bending	1. 08	5. 3. 2. 13. 1
Feathering Bearing	285-0513			
Housing Assy &	285-0532	Attachments	. 21	5. 3. 2. 14. 1
Attachment	285-0571			
Rotating Duct	285-0519	Tension	2. 42	5. 3. 3. 4. 1
Assy-Upper	285-0541			
See also Link Strap		Attachments	. 09	5. 3. 3. 6. 1
Stationary Duct	285-0522	Tension	1. 29	5. 3. 3. 9. 0
Assy-Lower				
Main Rotor Shaft	285-0517	Bending (Fatigue)	. 45	5. 3. 4. 1. 2
		Tension	. 72	5. 3. 4. 1. 4
Spoke	285-0515	Tension	. 21	5. 3. 4. 2. 2
Trunnion	285-0527	Compression	. 74	5. 3. 4. 6. 2
Gimbal Ring	285-0528	Bending	. 40	5. 3. 4. 7. 3

CONTROLS ANALYSIS

ITEM	DWG. NO.	TYPE LOADING	MIN M. S.	PAGE NO.
Control Rod	285-0305	Tension (Fatigue)	.52	5.4.3.1.0
Control Rod	285-0307	Tension (Fatigue) Column	.26 0	5.4.3.2.0 5.4.3.2.1
Upper Beam Assy	285-0337-7	Bending (Fatigue)	2.48	5.4.3.3.1
Lower Beam Assy	285-0337-3	Bending (Fatigue)	1.70	5.4.3.4.0
Upper Support Assy	285-0306	Bending (Fatigue)	High +	5.4.3.5 0
Rotating Swashplate	285-0312	Bending	3.12	5.4.3.6.5
Stationary Swash-plate	285-0313	Torsion	High +	5.4.3.6.8
Drive Line Assy	285-0335	Shear	.02	5.4.3.7.3
Link Assy	285-0336	Tension (Fatigue)	.16	5.4.3.8.0
Torque Tube Assy	285-0303	Shear (Fatigue)	1.28	5.4.3.9.1
Torque Tube Assy Shaft	285-0328-3	Bending (Fatigue)	2.22	5.4.3.9.4
Control Fitting Assy	285-0330	Tension (Fatigue)	1.77	5.4.3.10.1
Lower Controls Support Assy	285-0327	Tension (Fatigue)	.37	5.4.3.11.2

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